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WRIA 9 Strategic Assessment Report – Scientific Foundation for Salmonid Habitat Conservation

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WRIA 9
Steering Committee

and

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TABLE OF CONTENTS

SECTION 1 – INTRODUCTION 1-1
1.1. Overview 1-1
1.2. Background 1-1
1.2.1. Endangered Species Act Listing 1-1
1.2.2. WRIA 9 Reconnaissance Assessment 1-2
1.2.3. Puget Sound Regional Recovery Plan 1-2
1.3. Purpose of the Report 1-3
1.3.1. Guiding Principles for the Scientific Foundation 1-3
1.4. Study Area Description 1-4
1.4.1. Upper Green River Subwatershed 1-6
1.4.2. Middle Green River Subwatershed 1-6
1.4.3. Lower Green River Subwatershed 1-7
1.4.4. Duwamish-Elliott Bay Subwatershed 1-8
1.4.5. Nearshore Subwatershed (including independent tributaries to Puget Sound) 1-8
1.5. Overview of SA Report Sections 1-9
SECTION 2 – HISTORICAL HABITAT AND SALMONID POPULATION CONDITIONS 2-1
2.1. Introduction 2-1
2.2. Geologic and Glacial History 2-1
2.2.1. Puget Lowland Rivers 2-1
2.2.2. Green/Duwamish Watershed 2-1
2.3. Historical Habitat Conditions 2-3
2.3.1. Greater Duwamish Watershed 2-3
2.4. Historical Salmonid Populations 2-10
2.4.1. Chinook Populations 2-10
2.4.2. Other Salmonid Populations 2-13
SECTION 3 – CURRENT CONDITIONS – HABITAT, WATER QUANTITY, WATER QUALITY, AND SALMONID POPULATIONS 3-1
3.1 Introduction 3-1
3.2. Aquatic Habitat Conditions 3-1
3.2.1. Upper Green River 3-1
3.2.2. Middle Green River 3-3
3.2.3. Lower Green River 3-3
3.2.4. Duwamish River 3-4
3.2.5. Marine Nearshore 3-5
3.3. Water Quantity Conditions 3-6
3.3.1. Existing Water Quantity Conditions 3-6

3.3.2. Natural Flow Analysis Findings 3-7
3.3.3. Water Quantity Assessment 3-7
3.4. Water Quality Conditions 3-8
3.4.1. Water Temperature 3-8
3.4.2. Other Water Quality Parameters 3-11
3.4.3. Sediment Quality Conditions in the Duwamish River 3-15
3.5. Salmonid Population Conditions 3-15
3.5.1. Population Conditions 3-15
3.5.2. Current Population Conditions for Other Salmonids 3-21
SECTION 4 – COMPARISON OF HISTORICAL AND CURRENT SALMONID AQUATIC HABITAT CONDITIONS IN WRIA 9 4-1
4.1. Introduction 4-1
4.2. Methods 4-1
4.2.1. Historical Baseline Information 4-1
4.2.2. Assessment Reaches 4-2
4.3. Changes in Freshwater habitat 4-5
4.3.1. Upper Green River Subwatershed 4-5
4.3.2 The Mainstem Channel 4-5
4.3.3. Tributaries and Side Channels 4-7
4.4. Middle Green River Subwatershed 4-8
4.4.1. The Valley Bottom 4-8
4.4.2. Mainstem Channel 4-11
4.4.3. Tributaries and Side Channels 4-14
4.5. Lower Green River Subwatershed 4-15
4.5.1. The Valley Bottom 4-15
4.5.2. Mainstem Channel 4-18
4.5.3. Tributaries and Side Channels 4-19
4.6. Change in In-channel wood 4-19
4.7. Change in Riffle-Pool Sequence 4-21
4.8. Change in Estuarine Habitat 4-22
4.8.1. Duwamish Estuary Subwatershed 4-22
4.9. Elliott Bay 4-25
SECTION 5 – UPDATES TO SALMON ECOLOGY AND HABITAT USE IN WRIA 9 5-1
5.I. Introduction 5-1
5.2. Upper Green River Subwatershed 5-2
5.2.1. Juvenile Studies 5-2
5.2.2. Migration Timing and Fish Size 5-2
5.3. Middle Green River Subwatershed 5-2
5.3.1. Natural Juvenile Chinook 5-2

5.3.2. Natural Adult Chinook Spawning 5-3
5.3.3. Hatchery-Natural Chinook Interactions 5-4
5.3.4. Bull Trout Information 5-4
5.3.5. Other Fish Species Information 5-4
5.4. Lower Green River Subwatershed 5-5
5.4.1. Natural Juvenile Chinook 5-5
5.4.2. Hatchery-Natural Chinook Interactions 5-5
5.5. Duwamish River Estuary 5-6
5.5.1. Natural Juvenile Chinook 5-6
5.5.2. Hatchery-Natural Chinook Interaction 5-7
5.5.3. Bull Trout Information 5-7
5.5.4. Other Fish Species Information 5-7
5.6. Marine Nearshore (including Elliott Bay, Mainland, and Vashon/Maury Islands) 5-8
5.6.1. Natural Juvenile Chinook 5-8
5.6.2. Hatchery Chinook Interaction 5-9
5.6.3. Bull Trout Information 5-9
5.6.4. Other Fish Species Information 5-9
5.7. Limiting Factors and Viability Parameters Addressed by the Research Studies 5-10
SECTION 6 – FUNCTIONAL LINKAGES BETWEEN HABITAT AND SALMONID POPULATIONS 6-1
6.1. Purpose of the Evaluation 6-1
6.2. Ecological Synthesis Approach (salmon ecology and current versus historic habitat approach) 6-1
6.3. Conservation Hypotheses and Rationale 6-4
6.4. Guidelines for Research, Monitoring, and Evaluation 6-21
6.5. Guidelines for Adaptive Management 6-21
6.6. Next Steps 6-22
SECTION 7 – NECESSARY FUTURE HABITAT AND SALMONID POPULATION CONDITIONS 7-1
7.1. Introduction 7-1
7.2. Background and Guidance 7-1
7.3. Basis for Determining Necessary Future Conditions 7-2
7.3.1. Population Performance Findings 7-2
7.3.2. Spatial Structure Findings 7-3
7.3.3. Diversity Analysis 7-4
7.4. Necessary Future Conditions 7-4
7.4.1. Abundance Goals and Rationale 7-5
7.4.2. Productivity Goals and Rationale 7-5
7.4.3. Spatial Structure Goals and Rationale 7-6

7.4.4. Diversity Goals and Rationale 7-6
7.4.5. Further Rationale for Necessary Future Conditions 7-7
7.4.6. Necessary Future Habitat Conditions 7-8
7.5. Uncertainty in the Estimation of Necessary Future Conditions for Chinook Recovery 7-12
7.5.1. Sources of Uncertainty in the Data and Analyses. 7-12
7.5.2. Uncertainty and Necessary Future Conditions 7-14
SECTION 8 – SUMMARY, SCIENTIFIC FOUNDATION AND NEXT STEPS 8-1
8.1. Summary snd Scientific Foundation 8-1
8.1.1. Linking Conservation Hypotheses and Necessary Future Conditions 8-1
8.1.2. VSP Parameters Most Threatening Long-term Viability 8-2
8.1.3. Habitat Actions and Conservation Hypotheses that Affect VSP Parameters 8-3
8.1.4. Non-Habitat-Based Conservation Hypotheses That May Affect the Limiting VSP Parameters 8-13
8.2. Habitat Planning – Next Steps 8-13
REFERENCES R-1

TABLES

Table 2.1. A comparison of predicted escapement estimates and returns of adult Chinook, coho and steelhead from three historical perspectives for the Green River upstream of the Tacoma Headworks project. 2-15
Table 3.1. Summary of Temperature Ranges and Potential Impacts to Various Salmonid Life Stages (adapted from Ecology, 2002). 3-9
Table 3.2. Applicable Temperature Criteria per Location and Use Designation for Char, Salmon, and Trout (adapted from WAC 173-201A, 2003, Table 200 and 602). 3-10
Table 3.3. Water bodies monitored for the Green/Duwamish watershed water quality assessment identified on Washington state's 1998 303(d) list. 3-12
Table 3.4. Means of naturally spawning Chinook population estimates from varying sources. Time frames and what each data set includes is described. 3-16
Table 3.5. Adult recruits per adult spawner (R/S) from 1971 to 1998, broken into decades for Green River Chinook. These figures include a natural spawner adjustment for hatchery effectiveness of 1 3-17
Table 3.6. Relative distribution of Chinook redds (% of total) in the major basin of Green River 1997-2002. 1997-1998 data from Malcom (2000). 1999–2002 data from Martin et al. (2004). Both sources used WDFW spawner database. River Miles according to William et al. (1975). 3-18
Table 4.1. Assessment Segments of the Green/Duwamish River used to analyze aquatic habitat change. ([1] River miles are estimated from Williams et al., 1975) 4-3
Table 4.2. Total Area for Historical and Current Land Cover Area from river mile 32 to 45. 4-9
Table 4.3. Comparison of Mainstem Channel Area for Middle Green Assessment Segments 4-11
Table 4.4. Bankfull width change for segments within the Middle Green subwatershed. 4-12
Table 4.5. Sinuosity for segments within the Middle Green subwatershed 4-12

Table 4.6. Channel edge length for segments within the Middle Green River subwatershed 4-14
Table 4.7. Total Area for Historical and Current Land Cover Area from river mile 11 to 32..... 4-17
Table 4.8. Change in Channel Morphology for Segment 3 4-18
Table 4.9. Quantity of LWD pieces per meter for channels >20m in studies of unmanaged forests in Alaska and Washington. 4-20
Table 4.10. Pool Characteristics for Middle Green River Subwatershed. Data from R2 Resource Consultants (2002). 4-21
Table 4.11. Total Area for Historical and Current Land Cover Area from river mile 0.0 to 11..... 4-22
Table 5.1. Generalized Juvenile Chinook Timing and Size While Migrating out of the Middle Green River Sub-watershed 5-4
Table 5.2. Generalized Juvenile Chinook Timing and Size While Migrating out of the Lower Green River Subwatershed..... 5-6
Table 5.3. Generalized Juvenile Chinook Timing and Size During Downstream Migration Through the Green/Duwamish Estuary Sub-watershed 5-7
Table 6.1. Conservation Hypotheses 6-6
Table 8.1. Habitat Changes that Promote Improvements in VSP Parameters 8-5
Table 8.2. Types of Habitat Improvements Provided by Habitat Actions 8-7
Table 8.3. Draft Habitat Conservation Hypotheses That May Affect Spatial Distribution By Extending Access to New Habitats or Enhancing Spatial Structure in Currently Accessible Reaches 8-10
Table 8.4. Draft Habitat-Based Conservation Hypotheses That May Affect Productivity..... 8-11

FIGURES

Figure 2.1. Historical photograph of fish trap on a Green River tributary taken in 1923 near Auburn. 2-6
Figure 2.2. Historical tidal wetland complexes in Elliott Bay: (A) West Point (1867), (B) Smith Cove (1874), (C) Occidental Square tidal lagoon (1855-56) 2-10
Figure 2.3. Predicted core areas for Chinook salmon spawning in Upper Green River Subwatershed (Martin et al., 2004). 2-12
Figure 3.1. Current Spawning Distribution of Green River Summer/Fall Chinook 3-19
Figure 4.1. Assessment Segments for the Green/Duwamish River 4-4
Figure 4.2. Comparison of active channel width over time for the Upper Green River 4-6
Figure 4.3. Middle Green River Historical and Current Conditions 4-10
Figure 4.4. Lateral Channel Migration in Metzler-O'Grady reach. 4-13
Figure 4.5. Lower Green River Historical and Current Conditions 4-16
Figure 4.6. Duwamish Estuary Historical and Current Conditions..... 4-24

SECTION 1 – INTRODUCTION

1.1. OVERVIEW

The WRIA 9 Strategic Assessment Report represents a summary of the best available scientific information (i.e., the scientific foundation) that will be used to support development of actions in the WRIA 9 Habitat Plan that address salmonid conservation and recovery needs in the watershed. This report was developed by the WRIA 9 Technical Committee and reflects previous work from the *Reconnaissance Assessment* phase as well as extensive technical work carried out over the past four years (2001-2004) as part of the *Strategic Assessment*.

This report presents information regarding historical and current habitat conditions, salmonid population conditions, water quantity and quality. Specific information is included on fish utilization, including juvenile migration and rearing patterns, habitat usage, and habitat limiting factors. All of this information is used to examine the functional linkages between habitat conditions and populations and help guide the development of conservation hypotheses and habitat-planning actions. Finally, the report provides recommendations regarding necessary future conditions to support a viable population of Chinook salmon, as well as necessary future habitat conditions by subwatershed. The next step in the planning process is the development of subwatershed strategies that will guide the actions that will be part of the WRIA 9 Habitat Plan.

1.2. BACKGROUND

In 1999, Puget Sound Chinook salmon and bull trout were listed as threatened under the Endangered Species Act (ESA). The listing led to an extensive local and regional response at the watershed level to address habitat conditions. In the Tri-County area (Snohomish, King and Pierce counties), a process was developed to coordinate planning for salmon habitat conservation and recovery. This included a four-task approach, resulting in the development of scientific reports and action plans on the basis of watershed planning areas (or WRIAs). The 14 individual WRIA efforts are being coordinated by the Shared Strategy for Puget Sound and the Puget Sound Technical Recovery Team (TRT). The goal of the effort is to develop a recovery plan for the Puget Sound Evolutionarily Significant Unit (ESU) for Chinook and other species. The federal government has the legal authority to develop regional salmonid recovery plans; however Shared Strategy is taking the first step in "rolling up" watershed plans, with assistance from the Washington Department of Fish and Wildlife and tribal nations.

1.2.1. Endangered Species Act Listing

The National Marine Fisheries Service (now known as NOAA Fisheries) listed Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) as a threatened species under the Endangered Species Act (ESA) in March 1999. The U.S. Fish and Wildlife Service listed Coastal-Puget Sound bull trout (*Salvelinus confluentus*) as a threatened species under the ESA in November 1999. The Green/Duwamish and Central Puget Sound Watershed (WRIA 9) is within the geographic scope of the ESU of the Puget Sound Chinook listing and the Distinct Population Segment (DPS) of the Coastal-Puget Sound bull trout listing. While the emphasis of WRIA 9 planning efforts is listed species (particularly Chinook), the technical work was carried out to collect information on other salmonid species whenever feasible, given resource and funding constraints.

1.2.2. WRIA 9 Reconnaissance Assessment

The four-task approach to salmon habitat conservation has two phases with a scientific focus: the Reconnaissance Assessment and Strategic Assessment. For WRIA 9, the reconnaissance assessment consisted of two reports, completed in 2000 and 2001.

Habitat Limiting Factors and Reconnaissance Assessment Report. *(December 2000)* This scientific report brought together then-available information on conditions of salmon and salmon habitat in WRIA 9 both from the scientific literature and from local knowledge and expertise. It identified important problems and factors contributing to salmon decline. It also highlighted gaps in data and technical understanding. It was developed as a collaborative effort between the WRIA 9 Steering Committee and the Washington State Conservation Commission. It is available on-line at: http://dnr.metrokc.gov/Wrias/9/TechnicalReports/TechnicalReports.htm.

A similar type of report, completed in mid-2001, provided more detailed information on the marine nearshore ecosystem of Puget Sound. The Reconnaissance Assessment of the State of the Nearshore Ecosystem report is available on-line at: http://dnr.metrokc.gov/wlr/watersheds/puget/nearshore/sonr.htm.

The workplan for the Strategic Assessment was developed upon completion of these two documents to address key data gaps identified in these reports and to provide the scientific foundation for the development of the WRIA 9 Habitat Plan. The WRIA 9 Steering Committee provided direction for the substantial scope and approach to the science.

1.2.3. Puget Sound Regional Recovery Plan

The Shared Strategy for Puget Sound is a regional effort focused on the development of a collaborative Recovery Plan for Puget Sound Chinook and other listed species. The group represents tribes, federal, state and local governments working towards common objectives, as follows (Shared Strategy, 2001):

- The recovery and maintenance of an abundance of naturally spawning salmon at self-sustaining, harvestable levels;
- The broad distribution of naturally spawning salmon across the Puget Sound region; and
- Genetic diversity of salmon at levels consistent with natural evolutionary patterns.

The Shared Strategy effort is supported by the Puget Sound TRT. The Puget Sound TRT is an independent scientific body convened by the NOAA Fisheries to develop technical delisting criteria and guidance for salmon recovery planning in Puget Sound. The TRT serves as science advisors to groups such as WRIA 9 charged with developing measures to achieve recovery goals. Specifically, the TRT developed technical guidance for watershed groups in Puget Sound regarding integrated recovery planning for listed salmon (TRT, 2003). The document describes the biological content of a recovery plan to fulfill ESA requirements and address broader recovery goals. It also specifies that the approach to recovery planning should address the concept of a viable salmonid population (VSP), including the following four parameters: abundance, productivity, diversity and spatial structure (see below for more detail). Shared Strategy will present its plan to NOAA Fisheries, who will ultimately provide the official regional recovery plan.

1.3. PURPOSE OF THE REPORT

As noted above, the Strategic Assessment Report represents a summary of the best available scientific information and provides the scientific foundation for developing actions in the WRIA 9 Habitat Plan. The purpose of the report is as follows:

- To summarize the results of the technical work and research carried out from 2001-2004 that filled important information gaps, in particular those concerning the health of the Green River Chinook salmon population and the habitat upon which salmon depend,
- To provide the scientific foundation for the development of the WRIA 9 Habitat Plan based on the information collected as part of the Strategic Assessment work plan and from the Reconnaissance Assessment phase, and
- To refine the technical strategy for salmonid habitat conservation and recovery (WRIA 9 Technical Committee, 2003).

The report is intended to synthesize the multiple products from individual SA tasks into a usable format. The report has been referred to as a "coat" summarizing key research and technical work that is most significant for plan development. It is also designed as an executive summary of the most significant scientific information available in WRIA 9.

1.3.1. Guiding Principles for the Scientific Foundation

The approach and guiding principles used to carry out the scientific work in the Strategic Assessment were influenced by several previous decisions. These include: (1) the Viable Salmonid Population (VSP) framework (McElhany et al., 2000) and (2) the Habitat Plan Substantive Scope and Approach, approved by the Steering Committee in 2002, and (3) the technical guidance document developed by the TRT (2003) for integrated recovery planning noted above.

1.3.1.1. Viable Salmonid Populations (VSP) in WRIA 9

The VSP guidance (McElhany et al., 2000) was developed by NOAA Fisheries to guide conservation and recovery efforts. The VSP approach is intended to help establish delisting goals and ESU-specific delisting criteria. NOAA Fisheries will use this information to determine which and how many populations are necessary for a viable ESU. WRIA 9 technical work will help inform this determination. The VSP document contains guidelines for each parameter that a salmonid population must demonstrate in order to be considered viable. At the heart of the VSP concept are four parameters that describe a viable salmonid population:

- Abundance: defined simply as population size or numbers of fish at all life stages
- Productivity: defined as how well the population is "performing" in its habitat, or the growth rate of the population
- Diversity: defined as differences within and among populations in genetic and behavioral traits (e.g., life-history trajectories)
- Spatial Structure: defined as both the geographic distribution of fish in a watershed and the physical processes that lead to that distribution.

In the Strategic Assessment, information about these VSP parameters will be used to help guide our research efforts, development of conservation hypotheses, and to determine necessary future conditions to support viable salmonid populations.

1.3.1.2. Habitat Planning Approach

The WRIA 9 Steering Committee approved an overall approach to habitat planning in 2002. The Committee specified the following:

> The Plan will use an ecosystem approach to watershed management, with a focus on federally listed species. The process will include evaluation of ecosystem interactions, and the Plan recommendations will emphasize restoration of ecosystem processes where possible. This approach is expected to produce conditions that benefit all native aquatic species. Management of non-listed species will focus on preventing future listings and ensuring that protection of non-listed species is not put at risk.
>
> Because the Plan will use an ecosystem approach, the geographic area of focus will be the aquatic ecosystems within WRIA 9 and the landscape-level processes that affect these aquatic ecosystems. Where actions address listed species (Chinook and bull trout), the geographic area of focus would be the nearshore, mainstem river and tributaries where listed species exist or could occur in the future.

In conducting research and studies to fill in information and data gaps, the WRIA 9 Technical Committee conducted research focused on listed species following the Viable Salmonid Population guidelines. The Technical Committee also collected information on other salmonid species when feasible, within budget constraints. Data collection and analysis also incorporated information from other initiatives, such as the Green/Duwamish Watershed Water Quality Assessment.

Habitat plan goals were also established to guide the planning effort, as follows:

Overall goal: Protect, rehabilitate, and enhance habitat to support viable salmonid populations in response to Endangered Species Act listing of Chinook salmon and bull trout using an ecosystem approach. This approach will also benefit other non-listed aquatic species.

Specific Goals:

- Protect and restore physical, chemical, and biological processes and the freshwater, marine and estuarine habitats on which salmonids depend.
- Protect and restore habitat connectivity where feasible.
- Protect and improve water quality and quantity conditions to support healthy salmonid populations.
- Provide an implementable plan that supports salmon recovery.

1.4. STUDY AREA DESCRIPTION

WRIA 9 consists of the Green/Duwamish and Central Puget Sound watersheds (Figure 1.1). This watershed has seen some of the most intensive human development of any watershed in Puget Sound. The Green/Duwamish River flows over 93 miles from the Cascade Mountains to Seattle's Elliott Bay. The Central Puget Sound watershed consists of the short independent streams that drain to Puget Sound from Elliott Bay south to Federal Way, and the associated shorelines of Puget Sound. Vashon/Maury Island and its marine shorelines also are included in WRIA 9 for salmon habitat planning purposes. WRIA 9 is bordered on the north by the Lake Washington/Cedar/Sammamish watershed (WRIA 8) and to the south by the Puyallup/White River watershed (WRIA 10).

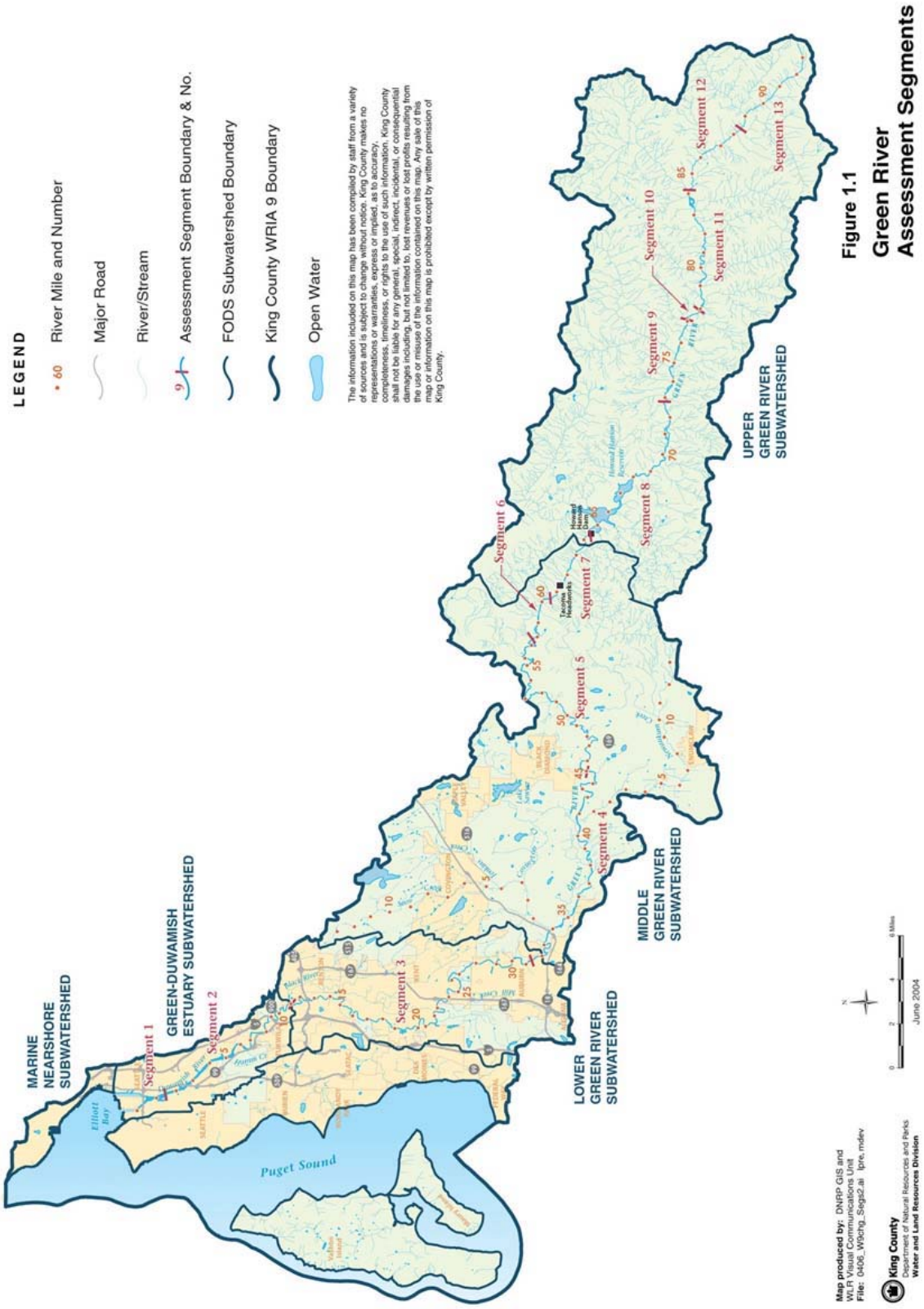


Figure 1.1
Green River
Assessment Segments

For planning purposes and to facilitate analyses as part of the Strategic Assessment, the watershed was divided into five subwatersheds: Upper Green River, Middle Green River, Lower Green River, Duwamish River, and the marine nearshore, including Elliott Bay. The following is a brief description of each subwatershed and associated anthropogenic influences.

1.4.1. Upper Green River Subwatershed

The Upper Green River subwatershed contains the headwaters of the Green River, which is in the vicinity of Blowout Mountain and Snowshoe Butte; it represents about 45 percent of the Green River's watershed area and stream mileage. The river flows generally west and northwest from the Cascades through approximately 25 miles of steeply sloped, densely forested terrain with narrow valleys. Howard Hanson Dam is immediately below the confluence of the North Fork with the Green River at approximately RM 64.5. Completed in 1962, the dam provides up to 106,000 acre-feet of water storage at an elevation of 1,206 feet. The primary land use in the Upper Green is forest (99 percent), and the upland vegetation is a patchwork of old growth, second growth, and recently logged areas. Tacoma Public Utilities draws its water supply from the Upper Green subwatershed, and operates a well field along the North Fork.

The two dams block upstream fish passage and the Howard Hanson dam severely hampers downstream fish passage, and sediment and large woody debris (LWD) transport from the upper watershed to lower reaches. The placement of roads and railroads immediately adjacent to rivers and streams in the upper subwatershed has reduced or degraded riparian habitat functions such as shade and large woody debris and resulted in numerous fish passage barriers. Streamside roads have also minimized the creation of new habitat by limiting lateral channel migration. Increased rates of erosion and alteration of sediment transport processes has also resulted in aggradation of reaches in the Upper Subwatershed that has in some instances resulted in flows going subsurface during the late summer (USFS 1996).

The reservoir pool has delayed juvenile outmigration and reduced spawning habitat and riparian functions due to periodic inundation of 4.5 miles of the Green River mainstem and 3.0 miles of tributaries. Logging practices near Green River tributaries have reduced riparian habitat functions (such as shade and instream large woody debris), increased sedimentation (in particular the introduction of fine sediments into the systems via on-going erosion), decreased water quality, and altered stream hydrology.

1.4.2. Middle Green River Subwatershed

The Middle Green subwatershed extends from Howard Hanson Dam (RM 64.5) to just downstream of the confluence of Soos Creek with the Green River at RM 32. Tacoma Public Utilities maintains its diversion dam at RM 61, where it diverts its drinking water. Below the diversion dam, the Green River flows between steeply sloped valley walls in mostly forested, mountainous terrain before emerging from the mouth of the Green River Gorge at the upstream end of Flaming Geyser State Park (RM 45.6). The river then flows through a broad valley down to its confluence with Soos Creek. However, levees and revetments constrain channel migration in significant portions of this reach without necessarily containing floods. Newaukum and Soos creeks are the major tributaries to the Middle Green. The Green River fish hatchery, built in 1904 and still in operation, is on Soos Creek. The major land uses in the Middle Green are residential-zoned land (50 percent), forestry (27 percent), and agriculture (12 percent). Much of the subwatershed is in unincorporated King County, but the cities of Covington, Maple Valley, Black Diamond, and Enumclaw contribute a more urban character to a portion of the Middle Green. The Urban Growth Area line bisects this subwatershed.

Dams, revetments, and residential and agricultural land use along the mainstem in this subwatershed have changed the natural flow regime, caused sediment starvation and scouring, reduced the amount and size of large woody debris, reduced channel complexity, reduced side channel and other off-channel habitats, and

reduced or degraded riparian habitat functions. Completion of Howard Hanson Dam in 1962 completely blocked sediment, especially gravel from the Upper Green subwatershed to the Middle Green and beyond. A gravel deficit has ensued (due to the fact that winter flows are strong enough to flush these sediments downstream without replenishment) resulting in channel incision and subsequent armoring. Based on an analysis of channel morphology and historic air photo sequences in the Green River, armoring is believed to have altered the reach between RM 61 and RM 57, and may be affecting the river downstream of the Green River gorge (Perkins 1993; Perkins 2000). Significant channel incision may reduce the amount of available rearing habitat by increasing the amount of time that side channels are disconnected from the mainstem during low flows. In portions of watersheds with significantly reduced sediment supply, the incidence of streamside landslides can increase. Landslides in the Middle Green River sub-watershed contribute material that is predominantly sand size or smaller (Perkins 1993). Because of this, coupled with a reduction in coarse sediment inputs from upstream, sand sized material now comprises a much larger proportion of the total bedload.

Residential, agricultural, and some urban developments along tributaries to the mainstem have reduced and degraded wetland and riparian functions. Similarly, these activities have reduced forest cover and increased impervious surfaces leading to hydrologic disruption to stream flow, channel degradation, increased sedimentation, and decreased water quality. Road construction and protection measures for private property have rechanneled streams and limited their lateral migration to facilitate use and development of lands adjacent to tributaries, as well as created barriers to fish passage. Residential, agricultural, and some urban developments along tributaries have also limited the amount and size of large woody debris and introduced non-native plant and animal species.

1.4.3. Lower Green River Subwatershed

The Lower Green subwatershed begins at RM 32 and extends downstream to RM 11. Springbrook Creek, Mill Creek and Mullen Slough are the major tributaries to the Lower Green. Historically, the White River, the Cedar/Black River and the Green River all joined in this reach to form a single large river. The White River joined the Green River near RM 31, and the Black River, which at the time also drained Lake Washington, joined the Green River at RM 11. In 1906, a logjam diverted the flow of the White River to the Puyallup River, and shortly thereafter, this arrangement was permanently engineered. Diversion of the White River, a glacially fed stream originating on Mt. Rainier, meant that in addition to a significant loss of flow and sediment, summer flows in the Green River were diminished by about half. The Cedar River was diverted from the Green in 1916 when the Ballard Locks were constructed and the level of Lake Washington was lowered. Together, these diversions resulted in a reduction of drainage area of about 70 percent.

After the diversion of the White and the Cedar/Black River, large earthen levees were built along the Lower Green River to further protect the valley from flooding. About 80 percent of the river upstream from RM 17 has a levee or revetment on at least one bank. These levees and other land use changes have reduced the amount of habitat available to salmon in the Lower Green, particularly refuge habitats. Residential development constitutes about half of the subwatershed area, with industrial and commercial development comprising an additional 27 percent. Mixed uses, parks, and agriculture comprise the remaining land uses. Jurisdictions located in the Lower Green subwatershed include the cities of Algona, Auburn, Federal Way, Kent, Renton, SeaTac, and Tukwila, and unincorporated King County.

Urbanization, water diversions, and revetments on the mainstem have gradually lowered the floodplain and resulted in disconnecting off-channel habitats such as sloughs and adjacent wetlands from the mainstem. Snagging efforts in several lowland rivers throughout the Puget Sound, including the Green/Duwamish drastically reduced accumulations of LWD in these rivers as well associated instream habitat complexity, such as pools and riffles. Urbanization and construction of flood-control levees and

revetments have limited LWD recruitment potential and have severely reduced riparian habitats and associated functions. Low flows, associated with water withdrawals and altered channel configuration have exacerbated low flow conditions, and contributed to adult salmon migration problems. These same human activities and developments in proximity to the mainstem have caused chronic water quality problems. Intense urbanization and infrastructure support near tributaries to the mainstem have resulted in impacts similar to those described for the Middle Green River subwatershed.

1.4.4. Duwamish-Elliott Bay Subwatershed

The Duwamish estuary begins at RM 11, at the upper limit of tidal influence and the historical confluence of the Black River with the Green River. The Duwamish River flows past scattered urban parks and single- and multi-family residences, as well as extensive industrial and commercial uses, on its way to Elliott Bay. The upper portion of the Duwamish has been diked and leveed to protect agricultural lands, while the lower Duwamish industrial area has been dredged and filled. Industrial (43 percent) and residential (39 percent) development is the primary land use in the Elliott Bay/Duwamish subwatershed. The subwatershed is primarily urban in character, and includes the cities of Tukwila and Seattle. Urban and industrial development practices on the mainstem have simplified and straightened the remaining channel, severely reduced riparian function, dredged, channelized, and filled 97 percent of the estuarine mudflats, marshes, and forested riparian swamps that formerly comprised the estuary. These ongoing development patterns and land uses have also significantly polluted or degraded water and sediment quality in the remaining channel via stormwater and wastewater effluents and historic industrial contaminants.

Development along tributaries to this portion of the mainstem has resulted in environmental impacts that are similar to those described for the Middle Green River subwatershed. In addition, extensive fragmentation and disconnection of remaining or marginalized habitats has occurred in this portion of the watershed.

1.4.5. Nearshore Subwatershed (including independent tributaries to Puget Sound)

The Nearshore subwatershed encompasses the Puget Sound shorelines of mainland WRIA 9, the streams that drain directly to Puget Sound, and Vashon/Maury Island. The northern boundary of the Nearshore subwatershed is West Point in the City of Seattle, and the southern boundary is just north of Dumas Bay in the City of Federal Way. Its seaward boundary is the outer limit of the photic zone (approximately 30m below mean lower low water), or the depth beyond which there is insufficient sunlight for active photosynthesis. The nearshore environment extends landward to include coastal landforms such as bluffs, sand spits, and coastal wetlands, as well as any marine riparian vegetation on or adjacent to these areas.

Residential development (68 percent) and industry (10 percent) are the primary land uses on the mainland portion of the Nearshore subwatershed. Residential development accounts for 92 percent of lands on Vashon/Maury Island. Most of the mainland portion of the subwatershed is incorporated into the cities of Seattle, Burien, SeaTac, Normandy Park, Des Moines, and Federal Way. Vashon/Maury Islands remain unincorporated. Urban and industrial land use near independent drainages or tributaries to the Puget Sound have resulted in environmental impacts that are similar to those described for the Middle Green River subwatershed. Development and shoreline modifications in nearshore areas have resulted in loss of nearshore habitat and marine riparian vegetation and disconnected nearshore habitats from habitat-forming processes (sediment sources, hydrology, riparian vegetation, etc.).

1.5. OVERVIEW OF SA REPORT SECTIONS

The following is an overview of Sections 2 through 8 of this Strategic Assessment Report.

Section 2 summarizes the historical and salmon population conditions in WRIA 9. It provides an overview of the geologic and glacial processes that formed the Puget Sound Lowland rivers as well as the Green/Duwamish Watershed; historical aquatic habitat conditions for each subwatershed; and historical population conditions for Chinook and other salmonids. Section 3 summarizes the findings on current conditions in WRIA 9, with an emphasis on aquatic habitat, water quantity, water quality, and salmonid population conditions. Some of the information is more focused on the Green/Duwamish River mainstem, such as the aquatic habitat reports, and some information is more watershed-wide, such as the water quality conditions reports.

Section 4 summarizes the analysis comparing historical and current habitat conditions. This comparison allows us to identify and quantify how aquatic habitats have changed over time, and it also provides information to support development of necessary future habitat conditions. Section 5 summarizes the findings of numerous independent salmonid studies carried out over the past four years and synthesizes and connects important information related to salmon ecology in WRIA 9. It builds upon the information presented previously in the Habitat Limiting Factors and Assessment Report (Kerwin and Nelson 2000). Studies carried out during or after the year 2000 were unique from past studies because in 2000 a program to mass mark juvenile Chinook released from the Soos Creek hatchery was initiated. Most of the studies focus on Chinook migration timing, relative abundance, and growth, which can be used to indirectly assess WRIA-wide habitat use.

Section 6 summarizes the functional linkages evaluation that explores the relationships between habitat conditions and salmonid populations and is one of the pivotal tasks in moving science to policy. The evaluation leads to the development of conservation hypotheses that provide a basis for habitat management strategies, management actions, and an adaptive management program. Section 7 summarizes the necessary future conditions to support a viable salmonid population (VSP) in WRIA 9 with a focus on Chinook. Using ecosystem and habitat guidance from many sources, VSP population goals are translated into targets for necessary future habitat that will be the basis for habitat management strategies and actions in WRIA 9.

Section 8 summarizes key findings from the Strategic Assessment and addresses key questions linking the conservation hypotheses developed in the Functional Linkages work to the VSP and habitat goals identified in the Necessary Future Conditions work. This provides the overall scientific foundation for the development of the WRIA 9 Habitat Plan.

SECTION 2 – HISTORICAL HABITAT AND SALMONID POPULATION CONDITIONS

2.1. INTRODUCTION

This section summarizes the historical and salmon population conditions in WRIA 9. It provides an overview of the geologic and glacial processes that formed the Puget Sound Lowland rivers as well as the Green/Duwamish/Watershed and Central Puget Sound; historical aquatic habitat conditions for each subwatershed; and historical population conditions for Chinook and other salmonids. Historical habitat and population information is drawn primarily from Historical Aquatic Habitats in the Green and Duwamish River Valley (Collins and Sheikh 2004), Upper Green Historical and Current Habitat Conditions (King County DNRP 2004), and Historical and Current Salmonid Population Conditions in WRIA 9 (King County DNRP 2004).

Information on historical conditions was used to compare with current conditions when available, and it also serves as a baseline for determining necessary future conditions presented in Section 7 and for setting recovery targets for the WRIA 9 Habitat Plan. Comparisons between historical and current conditions are presented in Section 4.

2.2. GEOLOGIC AND GLACIAL HISTORY

2.2.1. Puget Lowland Rivers

The Pacific Northwest has been the most geologically active of all areas in North America resulting in a high degree of environmental and habitat transformation. A series of tectonic, glacial and volcanic activities combined with dramatic climate change have been the primary processes forming the Pacific Northwest landscape. These processes in combination with rivers, landslides, waves, and volcanic mudflows determine watershed characteristics. The end result has been a wide variability in the physical and biological conditions of streams (Booth et al. 2003).

The two major valley types found in Puget Lowlands are Holocene and Pleistocene valleys. These valleys were formed during different time scales of geologic deposits and events that in turn created different river patterns and processes. Pleistocene valleys were created by subglacial runoff that incised into the Puget Lowland glacial fill during the last stages of the glaciation. They are generally wide, low-gradients valleys with a meandering river and a distinct meander belt that is built up above the floodplain by several meters. Floodplain landforms include oxbows, ponds, and extensive wetlands due to frequent flooding. In contrast, Holocene valleys were created later by post-glacial fluvial incision into lowland glacial fill. Holocene valleys are steeper with an anastomosing (or branching, multiple-channel) river pattern. These rivers migrate more dynamically that result in cutting off river bends and creating a network of side channels. Large woody debris (LWD) plays a more major role in the shaping of rivers in Holocene valleys (Collins et al. 2003).

2.2.2. Green/Duwamish Watershed

The Green/Duwamish Watershed began to form approximately 6 million years ago. Around this time, the Cascade Mountains were a line of fire up and down the coast as the oceanic plates were colliding and pushing up the continental plates. Molten rock from the earth's core pushed forth through the sandstone

and shales, erupting as lava that filled in the foothills and ash that covered the delta plain. Eventually, the volcanic activity slowed down leaving the Cascade Mountain steeper. The newly formed mountains were able to capture the rainfall and the ancient Green River was formed. The ancient rivers are believed to have flowed northwesterly meaning the Green River flowed where the present day Cedar River flows (Salo 1997).

Glaciers continued to shape the Green/Duwamish Watershed as they scoured, gouged, and polished the landscape that had been forming the 50 million years before. As the glaciers advanced, they deposited delta sand and rock. When they retreated, sea level rose filling the low areas with water, sand, and gravels. The last glacier, referred to as the Vashon glacier, began its retreat approximately 18,000 years ago. As it did, the lower Green River valley became a vast lake dammed at the north end by the ice and fed by the waters of the Cedar and Green Rivers; the White River flowed to the south at this point in time. The retreat of Vashon Glacier continued for about 8,000 years and eventually the Green River valley inland lake filled the Duwamish valley before it eventually receded into the new inland sea that the glaciers left behind (the area currently referred to as Elliott Bay and beyond that Puget Sound?). The melting of the glaciers caused the landmass to rise, producing some of the local geomorphology of the watershed. It was during this period that the early ancestors of the indigenous tribes were beginning to settle the Puget Sound Basin (Salo 1997).

Approximately 5,000 years ago, Mount Rainier produced the Osceola mudflow that resulted in approximately 2,000 feet of the mountainside collapsing. This mudslide flowed down from Mount Rainier through the White River valley forcing the White River north into the lower Green River valley. It carried with it volcanic and glacial debris that deposited through the valleys and pushed the inland sea back down the valley. The rivers during this period swelled with the heavy rainfall and melting of snow. As they flowed, they shaped the valley by carving through the glacial drift and depositing gravel, sand and silt. The rivers dynamically migrated around debris obstacles, uprooted trees, and flooded valley bottoms that filled depressional wetlands. When the lower Green (historically the White) and upper Duwamish Rivers overflowed their banks, sediments were deposited along their banks creating natural levees that prevented the water from returning into the rivers. Since the Green River was flowing through a steeper valley, it migrated more dynamically and created braided mainstem channels and numerous side channels (Salo 1997).

The Duwamish River valley exhibits different morphology and landform in the lower valley compared to the upper valley. The upper Duwamish valley has been aggrading whereas the lower Duwamish valley has been degrading since the late Holocene (Collins and Sheikh 2004). The elevated riverbanks in the upper Duwamish valley illustrates how this portion of the river has been aggrading for the last several hundred of years (Collins and Sheikh 2004). In contrast, the elevation of the riverbanks in the lower Duwamish valley is lower than the valley bottom. There is also a large terrace (or series of terraces) in the lower Duwamish valley that likely resulted from uplift associated with the Seattle Fault (~1,000 years ago) and downcutting of the degradational setting of the valley (Collins and Sheikh 2004). These terraces confined the river resulting in the estuary being relatively small considering the river's size (Collins and Sheikh 2004).

During this time of considerable change, Pacific salmon were evolving and developing traits to maximize their survival in different habitats. They needed to adapt to a landscape with high levels of spatial and temporal diversity, as well as a diversity of geologic, climatic, and biologic conditions. Eventually, around 3,000 to 5,000 years ago, the changing habitat and the evolving Pacific salmon converged into a ecological harmony. The result was a great abundance of fish that is ranked as one of the natural wonders of the world (Lichatowich 1999).

2.3. HISTORICAL HABITAT CONDITIONS

2.3.1. Greater Duwamish Watershed

Prior to European influence, the greater Duwamish watershed was approximately 4,077 km^2 (1, 575 sq. miles) and included the White River, Black River, Cedar River, Green River, Duwamish River, Sammamish River, and lakes Washington and Sammamish, as well as numerous other salmon spawning tributaries. The historical watershed contained approximately 3,060 km (1,900 mi) of streams accessible to fish (USACOE and King County 2000). By 1916, the historical watershed had been reduced by 70 percent and accessible streams reduced by 93 percent (USACOE and King County 2000). The White and Cedar rivers were reengineered and diverted in the early 1900s and the Duwamish River was straightened in 1906. The construction of the Ship Canal in 1916 lowered water levels in Lake Washington that lead to the dewatering of the Black River and blocked migration of salmonids to Lake Washington and Lake Sammamish.

The historical White River flowed northward to join the present-day Green River at river mile (RM)[1] 31.3 near Auburn (Collins and Sheikh 2004). The White River is located in the snowmelt transition hydroregion, and is therefore a mix of snowmelt and rainfall. This is preferred spawning habitat for spring Chinook. Rain-on-snow events routinely flooded the lower Green River downstream of the confluence. Since the White River was a glacially fed river, it carried large amounts of fine sediments that were deposited along the banks during overbank flooding events. This created a natural levee along the banks of the present-day lower Green River.

Historically, the Black River flowed out of Lake Washington into the Duwamish River and the Cedar River also flowed into the Black River. This allowed salmon to migrate up the Black River and into Lake Washington or into the Cedar River. From historical accounts and archeological records, we know that an abundant number of salmon took this route (Buerge 1985; Bagley 1929; Suckley 1874) to the natal rivers and lakes for spawning.

The following section focuses on the historical aquatic and riparian habitat conditions in the subwatersheds of the Green/Duwamish and Central Puget Sound watershed. For more detailed information, refer to Historical and Current Habitat Conditions Analysis for the Upper Green River Basin (King County 2004), Historical Aquatic Habitats in the Green and Duwamish River Valley (Collins and Sheikh 2004), and WRIA 9 Functional Linkages Evaluation – Phase 2 Report (Anchor and NRC 2004).

2.3.1.1. Upper Green River Subwatershed

The Upper Green River Subwatershed contains the headwaters of the Green River that originates on the western crest of the Cascade Mountains at approximately 1,700 meter in elevation. The dominant form of precipitation is snow, although rain-on-snow events also occur that produce high peak flows. Average annual precipitation for the watershed is 215 centimeters per year and mean annual snowfall at the Stampede Pass weather station is 2850 centimeters per year (Western Regional Climate Center 1998).

The upper subwatershed provided extensive spawning and rearing habitat for salmon and trout historically. There were approximately 7,735 kilometers (km) of mapped stream channels, including 267 km of fish-bearing streams (USFS 1996). Total channel area in 1901 was estimated at 154 ha and average

[1] River miles used throughout this report were estimated from "A catalog of Washington streams and salmon utilization, WRIA-09" by Williams et al. (1975).

channel width was 48 meters (King County 2004). The channel width from RM 83 to 85 was the widest at approximately 72 meters[2].

It is assumed that the upper watershed supported mostly juvenile spring Chinook, coho, winter and summer steelhead and resident trout, although the lower reach may have supported fall Chinook as well. Important overwintering habitat and refugia for these species included areas with reduced water velocities, relatively constant year-round temperatures, and protection from predators. Bjornn (1978) reported that spring Chinook salmon rely upon large cobble for overwintering habitat. This was likely one of the dominant substrate sizes in the mainstem channel. According to Cutler (2000), the presumed upstream extent of use by Chinook, steelhead, and coho of the mainstem was estimated to be approximately RM 91.8. This estimate was based upon identifying the location at which the channel gradient increased to over 12 percent. Other areas that may have been historically used by Chinook salmon include North Fork Green River, Sunday Creek, and Smay Creek and the lowermost portions of major tributaries to the mainstem Green River.

The subwatershed was heavily forested with mid to late seral species, 75 percent and 26 percent respectively, with less than 1 percent in early seral stage (USFS 1996). The 1891 General Land Office (GLO) surveys recorded the area as "Heavily timbered with hemlock, fir, cedar and pine. Dense undergrowth…with salal and huckleberry and vine maple." (Brown 1891).

Riparian vegetation was frequently characterized as a "Dense growth of alder, cottonwood, and maple on (valley) bottom" (Brown 1891). Brown also noted that, "The soil along the Green River and its tributaries and through the valley…is first class." Riparian vegetation commonly mentioned in the GLO notes includes alder (*Alnus rubra*), cedar (*Thuja plicata*), hemlock (*Tsuga heterophylla*), and maple (*Acer macrophyllum*). The minimum diameter size tree used as a bearing tree was 7.5 cm (Collins and Montgomery 2003), however, the smallest size tree noted for the Upper Green was 30 cm. The largest size diameter trees ranged from 90 – 182 cm and were predominantly cedar trees. Yew (*Taxus brevifolia*) and spruce (*Picea sitchensis*) trees were also infrequently mentioned.

Historically, large woody debris in the streams may have ranged from 240 to 2,080 pieces per kilometer (Cedarholm et al. 1989; Murphy and Koski 1989; Robison and Beschta 1990; Fox 2001). These quantities would have provided a critical structure and habitat complexity. Tree species contributing to LWD historically would have been cedar, hemlock, maple, yew, and spruce. Large woody debris (LWD), undercut tree roots, and undercut banks would also provide slower water areas with cover for protection from predators and these features would have likely been prevalent prior to land management in the upper basin. In addition, side channels were prevalent in most reaches along the mainstem river and would have historically provided slower water areas as refuge from winter flows for the smaller fry.

Brown (1891) describes wetlands near the confluence of the Green River and North Fork Green River as a "spruce and cedar swamp 27.50 chains" (approximately 550 meters wide). This location corresponds to two inter-connected swamps identified and mapped by the US Army Corps of Engineers, with a total size of approximately 32 ha (Sylvester and Carlson 1961). These wetlands were connected to the North Fork Green River by an outlet channel and likely provided rearing area and refuge from high flows for salmonids.

[2] Historical habitat estimates in this report are based on historical reconstructions that used a variety of sources (General Land Office Surveys, USGS Topographic Maps, Lidar, etc.). These estimates should be used cautiously since the survey methods were limited, and map sources were either incomplete or variable accuracy. Efforts were made to cross-reference sources; however, historical reconstructions will always be incomplete and subject to both known and unknown biases.

2.3.1.2. Middle Green River Subwatershed

The Middle Green Subwatershed historically provided excellent spawning and rearing habitat that supported multiple salmonid species. The mainstem channel flows through steep, confined valleys and unconfined, lower gradient valleys. From RM 32 to 45, the historical channel incised through the wide alluvial valley bottom while migrating throughout. This channel migration created a sinuous and braided channel, with significant amounts of off-channel habitat that was used for juvenile rearing. Historical reconstruction of the aquatic habitat shows that in the mid-1860s most of the off-channel habitat was located north of the mainstem channel. Total channel area in the mid-1860s for this river segment was estimated at 142 ha and average channel width was 66 meters (Collins and Sheikh 2004). The historical characteristics of the river suggest that mainstem channel edge habitat was abundant and pools were large and frequent (Figure 2.1). Historically, there was potentially 50 km (31 miles) of mainstem channel edge habitat (Collins and Sheikh, 2003).

The unconfined valley bottom, from RM 32 to 45, is about one-fifth as wide and five times steeper than the Lower Green River Subwatershed. The steepness of the valley makes side channels, tributaries, and large woody debris jams valuable as habitat because of the refuge it provides from high flow conditions. According to Collins and Sheikh (2003), there were approximately 29 ha of side channels in the Middle Green River, more than twice that was present historically in the Lower Green River. These numerous side channels provided potentially 52 km (32 miles) of channel edge habitat; the necessary refuge to escape high velocity flows that can result from the steep valley bottom that characterizes this section of the river. The mainstem channel of the Middle Green River would have also provided juvenile rearing habitat especially in shallow areas along the channel edge and within the large woody debris jams.

The upland forest cover was a late successional forest of western hemlock and Sitka spruce and human disturbance was minimal. The valley bottom was heavily forested with western red cedar, black cottonwood, Douglas fir, Sitka spruce, and bigleaf maple. The vegetation along the river and tributaries was dense and overhanging the low-water line as described in the mid-1860s GLO notes (Collins and Sheikh 2004). These tree species would have contributed to LWD within the river system and provided the habitat complexity needed to support a viable population.

Property of White River Valley Museum, Auburn

Figure 2.1. Historical photograph of fish trap on a Green River tributary taken in 1923 near Auburn.

2.3.1.3. Lower Green River Subwatershed

This section focuses on the historical aquatic and riparian habitat conditions in the Lower Green River Subwatershed with an emphasis on mainstem habitat from RM 11 to 32. For more detailed information, refer to Historical Aquatic Habitats in the Green and Duwamish River Valley (Collins and Sheikh 2004).

The wide, low-gradient valley bottom of the Lower Green River subwatershed was historically a mosaic of floodplain forest and wetlands. Black cottonwood (*Populus trichocarpa*) was the most abundant large diameter tree (Collins and Sheikh 2004). Other less abundant large diameter bearing trees in the Lower Green River valley bottom were western cedar (*Thuja aplicata*), Douglas fir (*Pseudotsuga menziesii*), and bigleaf maple (*Acer macrophyllum*).

The Black, White, and Green rivers were all tributaries of the lower Green River that resulted in frequent floods. During flood events, the Lower Green River overflowed its banks creating a network of ephemeral streams that fed the wetlands and tributaries within the valley. It is likely that some juvenile salmon were carried along in the floodwaters and eventually ended up in the tributaries, wetlands, and side channels. These historical areas likely provided refuge during flood events and served as rearing habitat.

Large amounts of sediment were also deposited along the stream banks creating natural levees that forced the floodwaters to flow along the channel edge until breaks in the levees were found (Chittenden 1907). The majority of the floodwaters flowed to the east and fed the Springbrook Creek drainage complex and re-entered the system through the Black River. The floodwaters from the historical White River fed the Mill Creek drainage complex that drained from the large alluvial fan at the mouth of the White River

canyon in Auburn. This alluvial fan is referred to as the White River fan and strongly influenced the valley's drainage network and dominated the channel network form for approximately two-fifths of the valley (Collins and Sheikh 2004).

The high discharge of the White River carried with it large amounts of sediment and LWD. The lower Green River channel was braided for the first one half mile downstream of the White River confluence and was double in width as compared to the middle Green River just above (Perkins 1993). Sand and gravel bars were common (15 ha) in the reach between RM 25 to 32 directly downstream of the White River confluence (USACE 1907). These gravel bars and LWD created shallow habitat for juveniles and morphological heterogeneity within the Lower Green. These geomorphic characteristics also created suitable spawning habitat that still persists today; however, the depositional process and replenishment of spawning gravels was significantly reduced after the diversion of the White.

Historically, riparian vegetation was dense and overhanging into the mainstem channel (Ober 1898) which provided refuge and prey for juveniles. It is likely that this vegetation also may have protected some juveniles during flood events. Overhanging vegetation within the mainstem channel edge habitat and accessible wetlands would have increased heterogeneity within the Lower Green River.

LWD occasionally interrupted river flow and created pool habitat in the Lower Green River historically. Information on historical in-channel wood is limited since snag removal by Army Engineers was sporadic in the watershed. Snagging operations clearly existed from 1893 to 1906, but it is difficult to ascertain which in-channel logs were the result of land clearing. The 1898 description of snags does inform us about the habitat-forming processes of these jams, such as the accretion of sediments and the formation of bars. Although the creation of pools is not described, it is reasonable to assume that they were also present and provided habitat to juvenile and adult salmon. At approximately RM 18, Hilbert et al. (2001) also describes the village of Stook that means "a big jam of logs" and that canoes had to be hauled around the jam. Many of the log jams described were very large and were sometimes colonized with vegetation, indicating that they were present for long periods of time.

In the mid-1860s, the mainstem channel was wide (~72 m) and covered about 316 ha. Although its general course has not been significantly altered, historically, the river migrated throughout the floodplain, leaving behind oxbows and wetlands. Tributaries provided important habitat and accounted for approximately one-third of total channel area and 62 percent of channel edge (Collins and Sheikh 2004). Most of the tributaries were connected to wetlands that were providing habitat, nutrients, and prey to the system. There were approximately 1,700 ha of wetlands.

2.3.1.4. Duwamish Estuary Subwatershed

The historical Duwamish River estuary was small relative to other estuaries in the Pacific Northwest, due to its unique topography (Collins and Sheikh 2004). The Duwamish River valley is relatively narrow and the presence of large terraces restricted the river in certain areas. The narrow floodplain in the upper part of the valley bottom likely funneled the floodwater from the watershed and resulted in overbank flooding and the creation of "swampy marshes" (freshwater wetlands). In 1906 flood records, 15 feet of standing water was documented, including 3.5 feet above the levees. It is likely that these types of events happened often and fed about 200 ha[1] of freshwater wetlands (Collins and Sheikh 2004). Similar to the Lower Green River, these floodwaters likely carried with them juvenile salmonids who would have used these wetlands as rearing habitat since they likely contained standing freshwater.

The valley bottom forest was diverse with red alder and Oregon ash being most abundant. Large hardwood trees were less abundant, therefore, western red cedar and Douglas fir (possibly misidentified and actually Sitka spruce) contributed most of the basal area and LWD. Black cottonwood was also present along the river and would have contributed to in-channel wood (Collins and Sheikh 2004).

At the lower end (north) of the river where it becomes tidally influenced, historically there were several types of tidal marshes that contained different plant communities. Collins and Sheikh (2004) classified them as riverine-tidal marshes, further refining them as emergent, scrub-shrub, and forested. These wetlands totaled approximately 166 ha in the mid-1860s. Filling of wetland and marsh habitats began in 1895. The historical extent of tidal flats roughly coincided with the outer limit of the land fill and development of the last century and a half (Collins and Sheikh 2004). There were approximately 175 ha of estuarine wetlands in the mid-1860s, primarily downstream of present day Kellogg Island.

Like many estuaries, there were likely many small, shallow channels that provided shallow water habitat protected from high river flows. Blind tidal estuarine channels provided the most channel edge on the Duwamish with the mainstem providing the next largest amount of channel edge habitat (Collins and Sheikh 2004). The total mainstem channel was about 220 ha in size and approximately 22 km in length.

No information is available on numbers and duration of use of juvenile Chinook salmon in the pristine Duwamish River estuary. However, information from other estuaries in the Northwest suggests it was an important rearing habitat for multiple life histories of Chinook salmon (Simenstad et al. 1982, Levings et al. 1989, Congleton 1981, Healey 1991). Chinook salmon utilize estuaries to acclimate to marine water and to grow in a relatively food-rich environment where predators are often less abundant. In general, smaller salmon (e.g., fry) are likely to rear in estuaries for longer periods before moving into nearshore marine areas of Puget Sound. Numerous small channels in the estuary were bordered by key dense marsh vegetation that contributed to the production of salmon prey.

2.3.1.5. Marine Nearshore Subwatershed

Although an historical habitat analysis of the complete WRIA 9 marine nearshore has not yet been completed, Elliott Bay to West Point was reconstructed (Collins and Sheikh 2004). There were three small tidal marsh complexes: West Point, Smith Cove, and the present-day Occidental Square area of Seattle (Figure 2.2). Smith Cove was the largest and protected at the mouth by a sand spit. The northern portion was a salt marsh (~18.9 ha) fed by a large tidal network that entered on the western side of the cove.

The Occidental Square area lagoon-marsh complex was present in 1855 but had been filled by 1875. A sand barrier with a central opening for tidal flow bounds the complex (2.6 ha) at its opening to Elliott Bay (Collins and Sheikh 2004). West Point marsh (6.8 ha) was completely bound by a sand barrier (2.4 ha) except a single channel that opened on the north side of the point. This marsh appears to have been diked and drained by 1899 (Collins and Sheikh 2004) (Figure 2.2).

Undeveloped shorelines in other parts of Puget Sound illustrate how shoreline modifications have reduced the diversity of shoreline habitats including mud flats, eelgrass meadows, sand spits, estuaries, beaches, and riparian areas. Moreover, historical habitats were largely unaffected by stormwater runoff, domestic sewage, or chemical contamination associated with industrial discharges.

In general, shallow water marine nearshore habitat was more prevalent historically in the WRIA 9 planning area than it is today. However, the extent of loss has not been carefully quantified. Shallow water nearshore habitats provide four main functions for juvenile salmonids: foraging areas, refuge from predators, osmoregulatory transition areas, and migration corridor (Simenstad 1982). These areas are important for prey production and serve as nursery areas, among other functions, for many species of fish and wildlife.

Most of the shoreline had forested riparian areas or early successional vegetation communities in areas with unstable slopes. Marine riparian areas influence the integrity of nearshore systems and are important

for prey production (directly through insect production and indirectly through organic inputs and shading forage fish eggs), slope stability, sediment control, habitat structure, and wildlife.

There was likely far more coastal wetlands and marshes associated with spits and barrier beaches. These areas are frequently associated with sub-estuaries. Sub-estuaries were more numerous and in a more natural state (e.g. Smith Cove, Raabs Lagoon). These areas provide a high level of habitat diversity for different life history stages of Chinook (e.g., fry migrants). Functions of these habitats include prey production, salmonid osmoregulation, overwintering habitat, detritus, and refuge.

Although some sub-estuary deltas and shorelines are primarily influenced by freshwater sediment inputs, most marine nearshore habitats are more affected by marine shoreline littoral drift (Williams et al. 2001). Historically, marine shoreline sediment transport processes were fully functional, delivering sediments to the beach at rates and volumes that created and maintained a diversity of beach/habitat types (e.g., barrier beaches, sand spits).

There are limited data on the historical distribution of submerged aquatic vegetation (SAV, e.g., eelgrass, kelp). However, it is believed that eelgrass and kelp have been reduced from historical levels since it is known that anthropogenic influences have reduced eelgrass and kelp in some specific areas. SAV is important to juvenile and adult salmonids for primary production, detritus, prey production, refuge from predators, rearing and feeding.

Almost no data exists to verify historical juvenile fish use. However, it is logical to assume that marine nearshore areas supplied the four currently accepted functions of the nearshore for juvenile salmonids noted by Simenstad (1982). It is also likely that the current sequence of outmigration was mostly similar to current conditions, with juvenile pink salmon appearing in the nearshore first, then moving offshore, followed by chum salmon, then coho, and then fall Chinook.

It is believed that forage fish stocks (herring, sand lance and surf smelt) have declined in numbers, though it is not possible to quantify historical population numbers. It is also clear that there have been shifts in the fish communities within Puget Sound. Many bottom fish (rockfish, Pacific cod, etc) have greatly declined in numbers (Puget Sound Water Quality Action Team 2002).

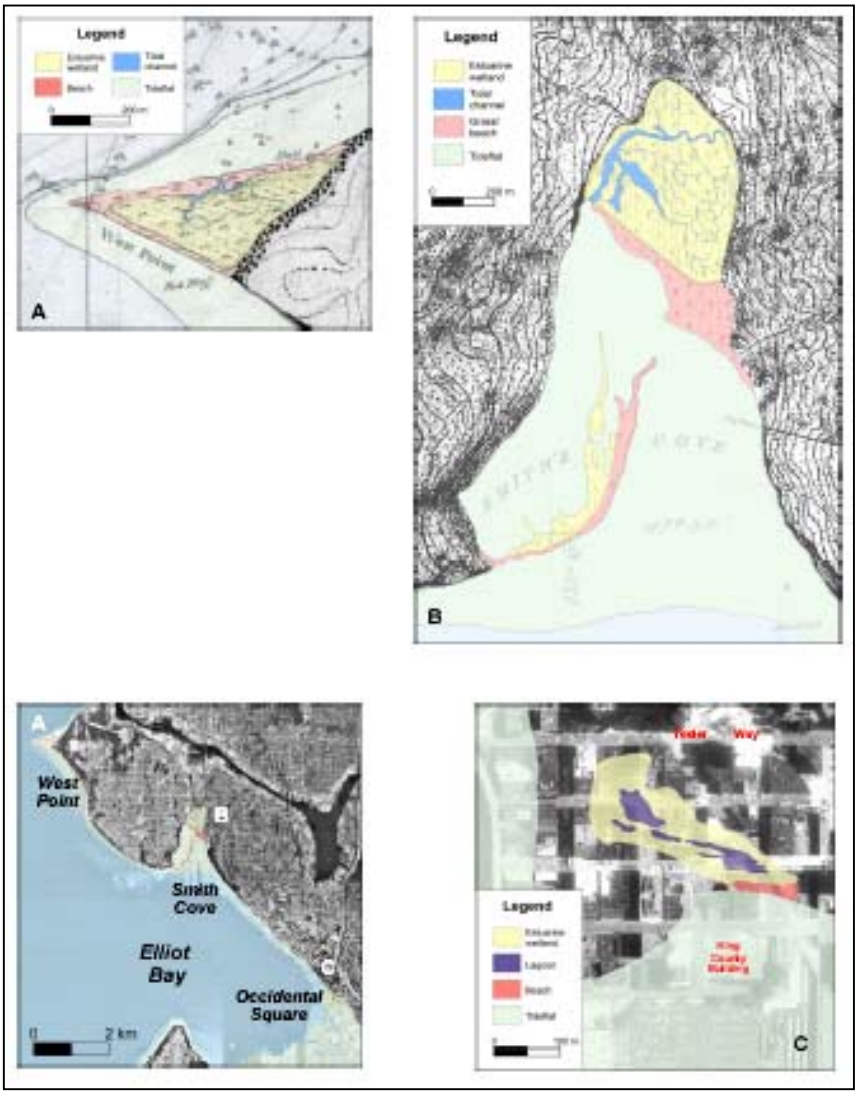


Figure 2.2. Historical tidal wetland complexes in Elliott Bay: (A) West Point (1867), (B) Smith Cove (1874), (C) Occidental Square tidal lagoon (1855-56)

2.4. HISTORICAL SALMONID POPULATIONS

The following section briefly summarizes information contained in the Historical and Current Salmonid Population Conditions for WRIA 9 (King County 2004). Refer to this report for further details and additional information on the historical Green River Chinook populations, as well as the other populations present in the greater Duwamish Watershed.

2.4.1. Chinook Populations

2.4.1.1. Abundance and Productivity

Historical abundance estimates for independent populations such as the Green River Chinook salmon are difficult to determine since the only available data beginning in the early 1900s is on fish catch or pack

data for Puget Sound as a whole and the data includes many non-Puget Sound salmon. Myers et al. (1998) reviewed fish canning data from the early 1900s and observed a peak harvest in 1908 that resulted in 95,210 cases of Chinook salmon being packed from Puget Sound. These numbers correspond to a peak Chinook run size of approximately 690,000. This estimate is confounded by the presence of Chinook salmon destined for natal rivers in British Columbia and the interception of Puget Sound-bound Chinook in Washington coastal troll and other fisheries. The former would inflate the estimate, and the latter would lead to an under estimate.

If 690,000 fish is used as launching point for historical peak catch of Chinook salmon, it may be possible to estimate historical abundance for the Green/Duwamish watershed. One method is to use comparative watershed size to determine the proportion of fish that entered each watershed. By using this means, we determined that the Green/Duwamish watershed represents approximately 5 percent of the total area of Puget Sound ESU. By applying this area ratio, the maximum historical run size estimate is approximately 37,700 Chinook, with a minimum run size of 9,000 to 11,000. Although watershed size was used, a more logical unit might be available spawning habitat; however, this data is not readily available at this time. While there are limitations and uncertainty to these estimates, they provide a reference for comparison to current population conditions.

No reliable historical information is available on productivity, in terms of recruits per spawner for Puget Sound Chinook. The best information available that can be used for representing historical productivity are the Chinook spawner abundance planning targets and ranges for the Puget Sound Region provided by the Puget Sound TRT (Shared Strategy 2002). Target maximum population growth rates have been identified that range from 2.3 to 3.8 recruits per spawner for various Puget Sound river systems.

2.4.1.2. Spatial Structure

The greater Duwamish watershed included the White River, Black River, Cedar River, Green River, Duwamish River, and Sammamish River, as well as numerous other salmon spawning tributaries. By 1916, the watershed had been reduced to 30 percent of its former size, thus greatly altering spatial structure. The White and Cedar rivers were reengineered and diverted in the early 1900s and the construction of the Ship Canal in 1916 lowered water levels in Lake Washington that led to the dewatering of the Black River and blocked migration of salmonids to Lake Washington and Lake Sammamish. The consequences of these changes to spatial structure also affected all the other viable salmonid population parameters: genetic and life history diversity, abundance, and productivity.

Historically, the spatial distribution for Chinook spawning in the Green River ranged from RM 24 to RM 91.3, including river reaches within the Lower, Middle, and Upper Green River Subwatersheds. Chinook spawning habitat also likely included larger tributaries such as Newaukum Creek, Sunday Creek, and possibly North Fork Green River (Fuerstenberg, pers. comm.). Channel morphology of the historical Green River was quite different than it is today, allowing for spawning patches that were likely larger and more dispersed.

Before construction of the City of Tacoma diversion dam in 1911, it is believed that Green River spring Chinook and possibly summer/fall Chinook used the Upper Green River Subwatershed for spawning and rearing. Without historical spawning data, we are basing our assumption of spawning distribution in the Upper Green River Subwatershed on the spawning patches predicted by Martin et al. (2004). This analysis used large-scale geomorphically significant characteristics and environmental processes to predict five distinct spawning patches along the mainstem in the upper watershed (Figure 2.3). These patches are approximately 3 to 5 km (2 to 3 miles) long and are separated by a similar length scale. The area flooded by Howard Hanson Dam was not examined in this analysis so it is highly likely that the upper watershed provided even more spawning patches. A conservative estimate based on Martin et al.

(2004) predictions is that the upper watershed provided 15 to 25 km (9 to 15 miles) of core areas of spawning habitat.

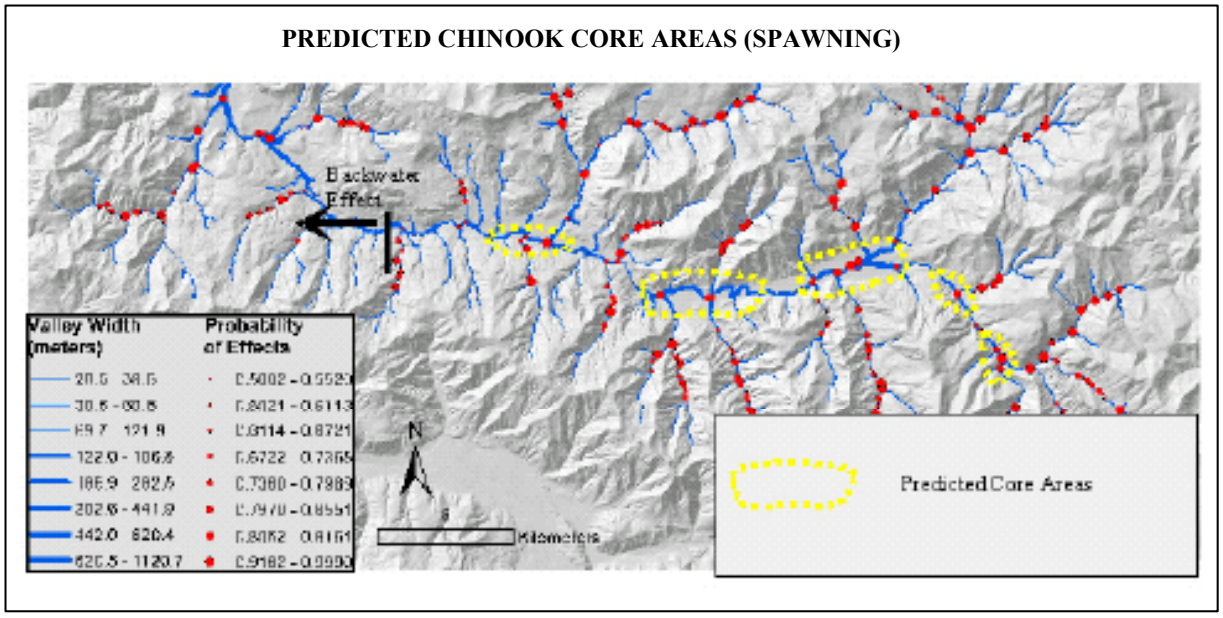


Figure 2.3. Predicted core areas for Chinook salmon spawning in Upper Green River Subwatershed (Martin et al., 2004).

The historical spatial structure of rearing habitat for the Green/Duwamish Chinook has not been previously documented, but juvenile salmonids would have utilized all parts of the watershed. As discussed, the aquatic habitats of the Green/Duwamish watershed included hundreds of ha of tidal wetlands and intertidal flats, hundreds of kilometers of a fairly dense network of tributaries and side channels, and a dynamic mainstem (Blomberg et al., 1988; Collins and Sheikh 2004; Kerwin and Nelson, 2000). Depending on the life history trajectory, the length of residence by juvenile salmonids in these aquatic habitats would have differed.

2.4.1.3. Diversity

Chinook salmon display the greatest diversity in life history patterns of the new world salmonids. According to Healey (1991), a life history [conceptual model] has two fundamental components: racial that is defined as related to "subdivisions of a population that are geographically separated to some degree and between which gene flow is reduced;" and tactical that refers to the adaptive variability to reduce the risk of mortality over time and across habitats, and is expressed in a variety of juvenile and adult behavioral patterns. Some examples of tactical traits are fecundity, run timing, spawn timing, juvenile behavior, age at smolting, age at maturity, ocean distribution patterns, and others (McElhany et al. 2000). The combination of these two components results in diverse and complex life history types.

Since there is virtually no reliable historical data or information on the life history of Green River Chinook salmon, a conceptual model was developed for historical diversity using assumptions based on current knowledge, hatchery records, and historical habitat conditions that likely existed prior to 1900.

The Green River is believed to have historically supported two independent populations of Chinook salmon, a stream-type and ocean-type (Nehlsen et al. 1991; WDF et al. 1993; Puget Sound TRT 2003). Stream-type Chinook salmon, commonly referred to as spring stocks, return to their natal river principally

in spring and early summer, several months prior to spawning. Ocean-type, commonly referred to as summer/fall stocks, principally enter freshwater during the late summer and fall, just a few days or weeks before spawning. These two races usually exhibit different juvenile life history types. The majority of stream-type juveniles typically spend a year or more in freshwater before outmigration to marine areas, while ocean-type juveniles normally outmigrate within several months of emerging from gravel. Ocean-type Chinook are larger than stream-type Chinook at every age class because stream-type Chinook grow at a slower rate during their first year (Healey 1991).

In addition to the two Green River populations, there were probably a minimum of three other independent Chinook populations within the greater Duwamish basin, including those in the Cedar River, White River, and North Lake Washington (King County DNRP 2004, Figure 14) (Puget Sound TRT 2001). However, the extensive use of Green River hatchery stock within the greater Duwamish basin to replenish depleted stocks has made it difficult to reconstruct the historical patterns of genetic similarity and divergence (Puget Sound TRT 2001).

For adults, variations in return and spawn timing are behavioral patterns that help to differentiate ocean-type from stream-type Chinook salmon, as well as create greater diversity within a population that can reduce its risk of extinction due to natural disaster. It is difficult to know for certain the historical return and spawn timing, but estimates were made using anecdotal information and hatchery records. Green River spring Chinook are believed to have entered the system from May to mid-June and migrated to the upper parts of the watershed to spawn from mid-June through September (Williams et al. 1975). The historical natural run timing of Green River summer/fall Chinook most likely ranged from late June through early November (Williams et al., 1975). Between 1905 and 1924, WDF operated a weir on the Green River mainstem near Big Soos Creek. This weir was installed in mid-August after the high spring flows to catch fall Chinook. It has been suggested that the hatchery practice of harvesting eggs from the first part of the run rather than throughout has shifted the return and peak times for the Green River fall Chinook. According to Miller and Stauffer (1967), hatchery fish returned two weeks earlier in the mid-1960s than they did in the mid-1940s. If this were the case, the natural return peak would have been near the third week of October (Grette and Salo 1986).

For juvenile salmon, variation in estuarine and freshwater residence time, and size at outmigration are aspects of juvenile life history diversity. Increased habitat diversity will increase the opportunity for juvenile Chinook to utilize these habitats, thus potentially increasing their residence time within the system. The combinations of these behavioral traits are expressed in multiple life histories shown by a population (Healey 1991). Lacking specific data on the historical life history diversity of Green River juvenile Chinook, it is our assumption that all the current five juvenile life histories would have been present historically in the Green River, with some trajectories being more common than they are today. It is possible that more variations existed historically given the complexity of habitat that was available.

2.4.2. Other Salmonid Populations

This section focuses on other historical salmonid populations that were present in the Green/Duwamish Watershed. In addition to spring and summer/fall Chinook runs, the Green/Duwamish Watershed historically was home to chum, pink, coho salmon, winter and summer steelhead, bull and cutthroat trout, and possibly sockeye salmon. When the historical Greater Duwamish Watershed is considered, almost all species of Pacific salmon and trout found in the Pacific Northwest used the Duwamish estuary for some part of their life. This section focuses only on those species that were only historically present in the current day Green/Duwamish Watershed. Most historical information was focused on those species that were being targeted by the hatcheries and therefore the information is limited. When historical information is lacking, the information presented is based on our general understanding of these fish species. When hatchery practices have not influenced a population, the current distribution and behavior

is presented as a close representation of historical conditions. Much of this information is limited to population abundance and distribution data available in the WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment Report (Kerwin and Nelson 2000).

2.4.2.1. Chum Abundance and Distribution

Historical information on Green River chum salmon (*Onchorhynchus keta*) is limited because there was little interest in culturing them. Today, the chum salmon that enter the Green River watershed are considered part of the South Puget Sound area chum stocks (Phelps et al. 1995). Two stocks are present in the Green River (WDFW and WWTIT 1994): Green River fall-run chum and Crisp Creek (also known as Keta Creek) fall-run chum. The origin of the Green River fall-run chum is an East Kitsap/wild remnant mix, while the Keta Creek fall-run stock originated from the Cowling Creek broodstock, whose origin is from Chico Creek in East Kitsap (Dorn 2000). Spawning information on the remnant mixed origin Green River stock is limited and no attempt is currently made to quantify current escapement estimates.

Historical run sizes and escapement estimates for chum salmon are more difficult to quantify. Spawner survey data go back as far as 1947 where 452 chum were observed in Burns Creek (Kerwin and Nelson 2000). Williams et al. (1975) reported an average annual escapement for the Duwamish/Green River basin of 11,300 for the years 1966–71 inclusive. There is no terminal area harvest data available prior to 1974 that would assist in determining run size to the Duwamish/Green River. Spawning ground counts for chum salmon are scarce. From the available information we were not able to determine historical run sizes or escapement estimates.

Typically, age of return for chum salmon adults varies from two to five years, but some can return as old as 7 years. They are second in size only to Chinook salmon. It was recorded that historically chum salmon entered Puget Sound rivers in autumn, generally appearing between September 15 and October 10 (Cooper and Stuckley 1859); however, this timing may vary for the Green River. Adults spawn successfully in a variety of stream sizes, including the mainstem channel and Puget Sound direct tributaries. When chum salmon fry emerge, they quickly outmigrate to the estuary for rearing. In the estuary, juvenile chum salmon follow prey availability. As food supply dwindles, chum move offshore and switch diets (Simenstad and Salo 1982).

2.4.2.2. Coho Abundance and Distribution

Coho salmon appeared to have been abundant in the Green/Duwamish Subwatershed relative to Chinook salmon and steelhead trout, based on historical escapement estimates. Although, hatchery practices were more focused on salmon as compared to steelhead, which may misrepresent species abundance (Grette and Salo 1986). These estimates were developed using numbers of females spawned at the Green River Eyeing Station 1911-1920, located at the Tacoma Diversion Dam. Historical escapement estimates for the Upper Green River Subwatershed ranged from 4,270 to 25,000 all of which are at least 30 percent higher than the highest estimates for Chinook salmon and steelhead trout (Table 2.1).

Table 2.1. A comparison of predicted escapement estimates and returns of adult Chinook, coho and steelhead from three historical perspectives for the Green River upstream of the Tacoma Headworks project.

Species	Grette and Salo (1986)	Riseland (1913)	Chapman (1981)
Chinook	No estimate	150 - 300	1,286
Coho	5,400 – 6,200	9,000 – 25,000	4,270
Steelhead	500 – 2,600	500 – 2,500	437

Coho salmon prefer smaller streams and side channels for spawning and rearing but will spawn in braided mainstem channels (Grette and Salo 1986). Juveniles will also rear in off-channel sloughs and wetlands, similar to those found historically in the Lower Green River Subwatershed. Since coho were collected at the Soos Creek Hatchery and the Green River Eyeing Station, it is reasonable that the historical distribution of coho salmon included the tributaries found in these areas. Other likely tributaries include Longfellow, Newaukum, Crisp, Burns, Springbrook, and Mill Creeks. Puget Sound direct tributaries on the mainland and Vashon/Maury Island were also likely used for spawning.

Based on population conditions today, it is possible that historically, sub-populations were found within the watershed. Today the coho salmon in the Green/Duwamish River basin are separated into two stocks (WDFW and WWTIT, 1994): Green/Duwamish and Newaukum Creek. Of particular interest is the significant difference in spawn timing between these two stocks that might be indicative of genetic differences. Coho returning to the Green River typically spawn up to mid-November. Newaukum Creek coho appear to spawn into mid-January (WDFW and WWTIT 1992, WDFW Spawning Ground Survey Database).

Coho return timing can range substantially between years depending on stream discharge. Adults typically mature by 3 years old, with a small portion spending an extra year in the ocean. Green/Duwamish River coho stocks typically enter freshwater from September to early December, but have been observed as early as late-July and as late as mid-February (MIT unpublished data). Spawning usually occurs between November and early February, but is sometimes as early as mid-October. Coho fry utilize shallow low-velocity rearing areas after emergence, and as they grow, juveniles move into faster water and disperse into tributaries and areas where adults cannot access (Neave 1949). Pool habitat is important not only for returning adults, but for all stages of juvenile development. Preferred pool habitat includes deep pools with riparian cover and woody debris.

Coho juveniles remain in the river for eighteen months after emergence. Juveniles are territorial which can lead to problems in rearing habitat availability. Summer low flows can exacerbate habitat availability problems and also result in increased stranding, decreased dissolved oxygen, increased temperature, and increased predation. Streams with more structure (e.g., logs, undercut banks) support more coho (Scrivener and Andersen, 1982), not only because they provide more useable habitat, but they also provide more food and cover. As coho juveniles grow into yearlings, they become more predatory on other salmonids. Green/Duwamish river basin origin coho begin to leave the river over a year after emerging from their gravel nests with the peak outmigration occurs in early May. Coho use estuaries primarily for interim feeding while they adjust physiologically to saltwater. In recent studies, the majority of juvenile coho salmon were observed in the Duwamish estuary in late May and early June (Nelson et al. 2004)

2.4.2.3. Pink Abundance and Distribution

Historically, the Green River supported a run of odd-year pink salmon (*Oncorhynchus gorbuscha*). This stock is thought to have become extinct in the 1930s (Williams et al. 1975), although personal observations by fisheries biologists in the 1990s confirmed the presence of small numbers of pink salmon adults in the mainstem Green River.

Based on current information, adult pink salmon return at two years of age and may have begun to enter the Green River mainstem in August and spawn in September and October of odd numbered years. Pink salmon fry likely emerged from redds around March and migrate downstream to the estuary quickly. Most of the juvenile rearing occurs in shallow marine nearshore habitats. After a limited rearing time in the estuary, pink salmon migrate to the ocean for a little over a year, until the next spawning cycle. In general, their time in freshwater as adults and juveniles is brief.

Little is known about historical distribution of pink salmon. It was recorded in 1928 (Maybury) that very few pinks are taken in the temporary racks across the Green River and it was also recorded that they do not "run" in Soos Creek on which the racks are permanent. However, this may be a result of a declining run rather than distribution.

An interesting piece of anecdotal information provided by Cooper and Stuck (1859) was "Hunnoh (pink salmon) come only every second year. The Indians say that when they do come there are always great abundance of salmon berries and other berries, and the summers are very warm."

2.4.2.4. Bull Trout Abundance and Distribution

Information on historical abundance and distribution of bull trout (*Salvelinus confluentus*) in the Green/Duwamish Subwatershed is extremely limited. The information that is available is often inconclusive due to the difficulty in clearly identifying this species from historical accounts. Suckey first observed native char in the Duwamish River during June 1856. He observed specimens as large as two feet in length in the Duwamish and another individual fish was captured approximately 35 miles upstream in June 1856 (Suckey and Cooper 1860). These fish were described as "red-spotted salmon trout" with the scientific name of *Salmo spectablis*. Pautzke and Megis (1940) described the presence of a "few" Dolly Varden during the 1930's in the Green River.

Bull trout in Puget Sound drainages exhibit four life history strategies: anadromous (migratory between saltwater and freshwater); adfluvial (migratory between lakes and rivers streams); fluvial (migratory within river systems); and resident (non-migratory). Resident fish tend to be smaller and slower-growing than migratory fish. Bull trout and Dolly Varden are closely related, but have been shown to be genetically distinct. However, due to the difficulty of distinguishing the two based on outward traits Washington Department of Fish and Wildlife manages bull trout and Dolly Varden together as "native char."

2.4.2.5. Steelhead Abundance and Distribution

Historical hatchery records provide some information on steelhead (*Onchoryhnchus mykiss*) (Riseland 1913; Darwin 1916; Darwin 1917; Darwin 1920; Darwin 1927); however, the hatcheries focused less on steelhead as compared to salmon (Grette and Salo 1986). Historically, there may have been two Green/Duwamish River steelhead stocks: a winter population and summer population. There continues to be a wild winter stock but the current summer stock is of non-native origin. Prior to 1966, sport angler punch cards indicated an annual summer steelhead harvest of small numbers (<12) fish per year (1962-66). SASSI (WDFW and WWTIT 1994) concluded that adult summer steelhead caught in the Green River basin were the result of strays from other systems or the result of adult winter steelhead caught during the summer steelhead management period (May 1 to October 31). However, the Green River Basin

is within the geographic range of summer steelhead, approaching the northern edge and it is possible that it may have had a small historical summer steelhead population.

Steelhead have one of the most complex life history patterns of any anadromous Pacific salmonid species (Shapovalov and Taft 1954). Green/Duwamish winter steelhead adults begin river entry as early as December in a near-mature reproductive state. Mature adults may be 3 to 7 years old, but age 4 and 5 fish generally predominate. They begin spawning in mid-March, but the majority spawn after April 1 (Grette and Salo 1986). Juvenile steelhead migrate to sea after one to three years of freshwater rearing, but a small proportion may reside in freshwater to become resident rainbow trout. Because of their prolonged freshwater residency, steelhead rely heavily on freshwater habitat.

Steelhead were likely widely distributed throughout the watershed. Hatchery records describe steelhead being trapped at Newaukum Creek, Big Soos Creek, and the Tacoma Diversion Dam. It is likely that steelhead used the mainstem up to its headwaters (RM 90), and Sunday Creek to its headwaters, as well as other larger tributaries, like Mill Creek and Springbrook Creek. They also would have used Puget Sound direct tributaries on the mainland and Vashon/Maury Island.

As mentioned in Section 3.3.2, historical hatchery practices tended to focus less on steelhead than salmon and therefore may not completely represent an accurate estimate of historical abundance. Several estimates have been made for winter steelhead escapement estimates for the upper subwatershed (Table 2.1). Estimates ranged from 437 to 2,400. According to the Grette and Salo (1986), the first affected year class impacted by the Tacoma Diversion Dam was in 1916.

2.4.2.6. Coastal Cutthroat Trout Abundance and Distribution

Coastal cutthroat trout (*Onchoryhnchus clarki clarki*) are a subspecies of cutthroat trout that are believed to have diverged into separate lines about 1 million years ago (Behnke 1997). Salmonid Stock Inventory (SaSI) (WDFW 2000) identified a distinct stock of coastal cutthroat trout in the Green River Basin and the NMFS ESU for coastal cutthroat trout includes the Green River Basin (Johnson et al 1999). In the NMFS coastal cutthroat status review, Johnson et al (1999) indicated that few data were available concerning historical and current abundance of coastal cutthroat trout in the ESU.

Assessing populations of coastal cutthroat trout in the Green River Basin is particularly difficult (Kerwin and Nelson 2000). A reduction in habitat capacity within the Puget Sound ecoregion has been widespread as streams were extensively modified beginning in the late 1800s and continuing through today. NMFS found that the scarcity of information available made risk assessments extremely difficult for coastal cutthroat trout. In SaSI (WDFW 2000), it was the conclusion of the editors that the stock status of Green River coastal cutthroat complex was unknown. The only data cited was limited electrofishing surveys conducted in Newaukum Creek.

Sea-run coastal cutthroat trout are found year round in shallow water close to marine nearshore areas. Smolts generally migrate from fresh water to marine nearshore areas in the spring at two to three years of age (Trotter 1989). Most anadromous cutthroat trout, having migrated in spring, return to their natal stream to spawn in the following year. Spawning may begin as early as December and continue through June, reaching a peak in February (Trotter 1989).

Resident coastal cutthroat trout are currently the most widely distributed salmonid in WRIA 9. It is likely that the historical distribution of cutthroat trout would have been similar to what is seen today. Cutthroat trout have been observed on the mainstem up to the Green River headwaters (RM 93), and major tributaries in the Upper Green River Subwatershed, including North Fork Green River, Sunday Creek, and Smay Creek. They are found in Longfellow Creek, Newaukum Creek, Soos Creek and its larger

tributaries, Mill Creek and Springbrook Creek. They are also present on multiple small tributaries on Vashon/Maury Island, as well as Judd and Shinglemill creeks.

SECTION 3 – CURRENT CONDITIONS – HABITAT, WATER QUANTITY, WATER QUALITY, AND SALMONID POPULATIONS

3.1 INTRODUCTION

This section summarizes the findings on current conditions in WRIA 9, with an emphasis on aquatic habitat, water quantity, water quality, and salmonid population conditions. This information is drawn from the Reconnaissance Assessment Report (Kerwin and Nelson 2000) and numerous Strategic Assessment reports (King County WLR 2004a, R2 Resource Consultants 2002, Anchor Environmental 2004a, Terra Logic and Landau 2004, Anchor Environmental 2004b, Taylor Associates and King County WLR 2004, Herrera Environmental 2004, King County WLR 2004b). Some of the information is more focused on the Green/Duwamish River mainstem, such as the aquatic habitat reports, and some information is more watershed-wide, such as the water quality conditions reports. Because of time and resource constraints, information on nearshore habitat conditions and water quantity conditions is incomplete. In such cases, existing information is presented and a summary of ongoing work is provided.

Information on current conditions was used to compare with historical conditions when available, and it also serves as a baseline for monitoring changes over time as the WRIA 9 Habitat Plan and related actions are implemented. Comparisons between historical and current conditions are presented in Section 4. The conservation hypotheses summarized in Section 6 and the necessary future conditions presented in Section 7 also build upon the current conditions presented here.

3.2. AQUATIC HABITAT CONDITIONS

Mainstem Green/Duwamish River habitat conditions were presented in Part II, Section 2 of the Reconnaissance Assessment report (Kerwin and Nelson 2000). This included sections on hydrology, sediment transport, hydromodification, riparian conditions, fish passage, and non-native species. Information on the mainstem was presented by subwatershed (Duwamish Estuary, Lower, Middle and Upper Green River). Part II, Section 3 contained detailed information about tributary conditions. As part of the Strategic Assessment, aquatic habitat assessments were carried out on the mainstem for the Middle Green River (R2 Resource Consultants 2002), Lower Green River (Anchor Environmental 2004a), Duwamish River (Terra Logic and Landau 2004), and for the marine nearshore (Anchor Environmental 2004b). Limited aquatic habitat information was available for the Upper Green River (King County WLR 2004a).

3.2.1. Upper Green River

This section focuses on current aquatic and riparian habitat conditions in the Upper Green River subwatershed with an emphasis on mainstem habitat. Additional information on the Upper Green subwatershed can be found in sections 1.4.1 (general overview) and 2.3.1.1 (historical habitat conditions). Channel characteristics vary by reach and were calculated from the 1998 mapped channel location (King County WLRD 2004). There are five assessment segments within the Upper Green River from RM 64.5 to 88.3.

Segment 8 (RM 64.5 to 72.7) is the lowest segment of the Upper Green River. The lower reach of Segment 8 consists of those areas between RM 64.5 – 69 that are completely inundated or seasonally

inundated by Howard Hanson reservoir. Immediately upstream of the reservoir influence, the channel has increased substantially in width. The North Fork Green River is a major tributary within this segment. The valley bottom consists primarily of mixed deciduous and conifer forest. No predicted core areas for spawning were identified within this segment (Martin et al. 2004). The channel width has increased substantially over time in this segment due to reduced sediment transport above the reservoir, logging within the riparian corridor, and sediment deposition from forest roads. The channel is constrained along approximately 22% of the channel length from railroad lines, and logging roads prevent lateral channel migration. Most of the mass wasting events identified were within the North Fork Green River and associated with roads that were found to contribute sediment directly to streams.

Segment 9 (RM 72.7 to 77) has the following characteristics: from RM 72.7 to RM 75.5, the segment is unconfined and flows through a low gradient, broad alluvial valley. The gradient increases between RM 75.5 and 77 to 0.9%, and the channel continues in a sinuous pattern. The segment contains a predicted core area for spawning from approximately RM 72 to 75.5 (Martin et al. 2003). The channel is confined by the railroad line and/or roads along 22% of the channel length. Historical side channels may have become disconnected from the mainstem channel. Recent surveys conducted from RM 70 to 75.5 found an average of 4.5 pieces of LWD (>30.5 cm diameter and 9.1 meters long) per kilometer with much of the LWD (89%) not functioning within the bankfull channel (USACOE 2002).

Segment 10 (RM 77 to 77.9) is a confined segment that flows through a steep, gradient (0.6%) floodplain. This reach appears to be effectively transporting sediment and channel width has decreased over time. This reach has a straight channel pattern and lacks channel bars. There were no core areas for spawning predicted within this segment. This segment is naturally lacking habitat complexity and does not appear to be storing gravels suitable for spawning. Recent inventories found 21 pieces of LWD/km (Toth 1997) within this segment. Historical side channels may have become disconnected from the mainstem channel. The reduction of channel sinuosity over time may be a result of loss of LWD in this reach due to transport of wood downstream and harvest of riparian timber stands.

Segment 11 (RM 77.9 to 84.1) is located within glacial alpine deposits and the channel is unconfined within the valley bottom, with a gradient of 0.8%. Approximately 75% of the upper portion of this reach (RM 83 to 84.1) is comprised of point, medial, and multiple bars with sediment derived from Sunday and Twin Camp Creeks. Two core areas for Chinook spawning were predicted within this segment. Portions of RM 77-83, inventoried as part of the Lester Watershed Analysis, had between 21 and 68 pieces LWD/km in two reaches using a minimum size of 10 cm diameter and 1 m long (Toth 1997). Historical side channels may have become disconnected from the mainstem channel. Increases in channel width and channel bars may indicate a loss of pool habitat within this segment.

Segment 12 (RM 84.1 to 88.3) is a confined segment with inclusions of lower gradient, broad alluvial valley portions. The channel pattern is generally straight throughout this segment. Two core areas for spawning are predicted. Roads constrain the mainstem channel in several segments. Rearing habitat is generally good, spawning habitat is poor to fair. There are low amounts of LWD, with no key pieces. Sediment from timber harvest and associated logging roads contributes sediment to streams.

Forestry continues to be the primary land use in the upper watershed. Current forest conditions in the upper Green River sub-watershed are primarily in early seral (40%) and mid seral (50%) stages, with 10% of the sub-watershed in late seral stage. Much of the existing late seral forest stands are located in riparian areas within headwater streams or areas of very steep slopes. Much of the riparian corridor was harvested during the original timber harvest and or burned in fires at the turn of the century (Faulkner 1997). Currently, riparian vegetation along the mainstem Green River is predominantly small to medium-sized deciduous or mixed deciduous and coniferous stands with less than 1% of the riparian zone in pure coniferous stands (King County 2000). The area immediately surrounding Howard Hanson reservoir is bare ground due to seasonal inundation.

3.2.2. Middle Green River

This section focuses on current aquatic and riparian habitat conditions in the Middle Green River subwatershed, with an emphasis on mainstem habitat. Additional information on the Middle Green subwatershed can be found in sections 1.4.2 (general overview) and 2.3.1.2 (historical habitat conditions). Channel characteristics vary by reach and were monitored as part of surveys performed in late summer 2001 (R2 Resource Consultants 2002). There are four assessment segments from RM 31.3 to 64.5

Key habitat attributes were monitored in six reaches of the Middle Green River (RM 32 to 64.5) including bankfull width, canopy cover, pool habitat (location and dimensions), LWD, and riffle particle size distribution. The bankfull width ranged from 33 to 45 meters in the Middle Green River. Canopy cover was generally about 15%, except in Segment 5 (Green River Gorge, RM 45.1 to 57.6) where it averaged 26%. Pool spacing ranged from nine channel widths per pool in Segment 5 to 34 channel widths per pool in portions of Segment 4 (Middle Green Valley, RM 32 to 45.1). Pools represented about 18 to 27% of the total habitat area, except in the upper portions of Segment 4 (RM 40 to 45), where pools represented only six percent of the area. LWD (minimum size of 10 cm diameter and 3.65 m long) was most common in the lower reaches of Segment 4 (RM 32 to 40), which contained several log jams composed of more than 100 pieces of LWD. LWD ranged from 14 pieces/km between RM 32 and 40, and 4 pieces/km in Segment 7 (Eagle Gorge, RM 60.5 to 64.4) (R2 Resource Consultants 2002).

Gravel was abundant between RM 32 and 45, where dominant riffle particle size was 42 to 69 mm. Substantial amounts of gravel were present in pool tailouts, small point bars and along channel margins downstream of a large landslide near RM 49. Upstream of RM 49, gravel was scarce, consisting mostly of cobbles due to the loss of gravel recruitment from above the Howard Hanson dam over the past 40 years. In Segments 6 and 7 (RM 57.6 to 64.4), gravel deposits at pool tailouts were rare and several low gradient riffles were largely devoid of gravel.

Current valley bottom conditions in Segment 4 (RM 32 to 40) were summarized as part of the change analysis for the Middle Green River (King County WLR 2004c). The valley has experienced significant land cover change, as compared to the narrow valley floor of the other assessment segments of the Middle Green. The average floodplain width is approximately 0.8 km. Elevation ranges from 17.5m to 70m. The forest that once covered the valley bottom has become fragmented and only about 40 percent of the valley bottom remains forested. Currently, there are few old growth trees and deciduous tree species are dominant. The agricultural production district comprises 74 percent of the valley bottom. As a result, more than half of the forested valley bottom (636 ha) has been converted to agricultural uses. An additional 3 percent has been cleared for residential development. Most of this development is occurring below Soos Creek near Auburn. The road density is 4.8 km/square km within the valley bottom, and there are eleven road crossings within this segment.

Two major sub-basins are located in the Middle Green subwatershed: Newaukum Creek and Soos Creek. A summary of habitat conditions in Soos Creek and Newaukum Creek is provided in Chapters 3.7 and 3.8, respectively, of the Reconnaissance Assessment Report (Kerwin and Nelson 2000), including information on morphology, riparian conditions, LWD, sediment conditions, off-channel habitat, and floodplain connectivity. No additional habitat information was collected as part of the Strategic Assessment.

3.2.3. Lower Green River

This section focuses on current aquatic and riparian habitat conditions in the Lower Green River subwatershed, with an emphasis on mainstem habitat. Additional information on the Lower Green River subwatershed can be found in sections 1.4.3 (general overview) and 2.3.1.3 (historical habitat conditions). Channel characteristics vary by reach and were monitored as part of surveys performed in late summer

2003 (Anchor Environmental 2004a). There is just one assessment segment in the Lower Green River from RM 11 to 32.

Key habitat attributes were monitored in four reaches of the Lower Green River (RM 11 to 32) included bankfull width (ordinary high water mark width, OHWM), bank conditions (type, height and armoring), canopy cover, riparian vegetation (type, quality, and overhanging), pool habitat (location and dimensions), LWD, and riffle particle size distribution. In general, the habitat conditions observed during the survey reflect extensive alterations to the Lower Green River floodplain that have resulted from dam operations, and urban, commercial and agricultural development. The following is a summary of findings of the survey (Anchor Environmental 2004a):

- Instream habitat quality and quantity for juvenile and adult salmonids is significantly imparied
- The channel is confined throughout the Lower Green, with extensive riprap bank armoring
- Habitat types are generally homogenous and off-channel habitat is limited
- The dominant pool forming factors are manmade structures, such as bridge abutments
- Spawning size gravels occur only in the upper third (RM 25-32) of the river
- The connectivity between the riparian zone and instream habitats is limited by levees
- The adjacent riparian zone is dominated by invasive species and lacks native vegetation
- Numerous stormwater and tributary outfalls of varying size discharge to the river

Anchor Environmental (2004) summarize conditions in the Lower Green by noting that the gradual channelization of the Lower Green River in the last century has resulted in substantial losses in quality and quantity of mainstem spawning, winter rearing, summer rearing, and adult holding habitat. Encroachment of land use, roads, trails, and levees to the river margins has greatly reduced the extent of existing or potential riparian habiatat. Bank tree cover is sparse, and the existing non-native vegetation provides little cover for fish.

The average OHWM width ranged from 26 to 39 meters in the Lower Green River. Median canopy cover varied from 34 to 44% in the different reaches (Figure 5-5, Anchor 2004a). Large pool (width greater than 50% of the OWHM width) spacing ranged from 16 channel widths per pool from RM 26.6 to 32.1 to 254 channel widths per pool from RM 11.2 to 15.6. Large pools represented between 10 and 16% of the total habitat area from RM 15.6 to 32, but less than one percent from RM 11.2 to 15.6 (Figure 5-1b, Anchor 2004). The dominant pool-forming factor throughout most of the river was riprap. Total wood pieces (logs and rootwads) ranged from 11 pieces/km between RM 26.6 and 32, and 43 pieces/km between RM 15.6 and 19.1 (Figure 5-6, Anchor 2004a). Log jams were only found between RM 19.1 and 26.6, with two observed.

Gravel was most abundant between RM 26.6 and 32, where the dominant riffle particle size was 50 mm and there were 17 gravel storage sites (Figure 5-7, Anchor 2004a). Between RM 19.1 and 26.6, the dominant riffle particle size was 22 mm and there were four gravel storage sites. Downstream of RM 23.3, the substrate is dominated by sand and silt sized particles. The dominant riparian vegetation is mature and native from RM 26.6 to 32 (Figure 5-3, Anchor 2004a). Downstream of RM 26, the riparian vegetation is dominated by invasive species.

3.2.4. Duwamish River

This section focuses on current aquatic and riparian habitat conditions in the Duwamish River subwatershed, with an emphasis on mainstem habitat. Additional information on the Duwamish River

subwatershed can be found in sections 1.4.4 (general overview) and 2.3.1.4 (historical habitat conditions). Channel characteristics vary by reach and were monitored as part of surveys performed in 2003 and 2004 (TerraLogic GIS and Landau Associates 2004, Anchor Environmental 2004a).

Key habitat attributes (as noted above in Lower Green River section) were monitored in one reach of the upper Duwamish River (RM 5.7 to 11.2) by Anchor Environmental (2004a). Habitat attributes in the lower Duwamish River (RM 0 to 5.7) were inventoried by Terralogic and Landau Associates (2004). Habitat attributes included riparian vegetation, invasive species, overwater structures, bank armoring, LWD, pilings, and hand launches. The assessment of habitat attributes included a 3-day field survey of the study area and aerial photo interpretation. In general, the habitat conditions observed during the survey reflect extensive alterations to the upper and lower Duwamish River.

The average OHWM width was 50 meters in the upper Duwamish River. There were three large pools (width greater than 50% of the OWHM width) with a spacing of one pool per 59 channel widths. Riprap was the dominant pool-forming factor and large pools represented three percent of the total habitat area. There was an average of 37 wood pieces/km in the Upper Duwamish. The median overhanging vegetation for both banks was two percent.

The assessment of habitat attributes in the lower Duwamish (RM 0 to 5.7) was completed from field surveys of the study area and aerial photo interpretation (Terralogic and Landau 2004). Summary results showed that over 90% of the lower Duwamish is armored (60% with riprap and 24% with steel or concrete bulkheads). Approximately 48% of the shoreline has no vegetation and 30% is blackberry; nearly 10% is landscaped/ornamental and six percent is other invasive shrubs; only three percent is immature deciduous vegetation. Approximately 87% of the shoreline has greater than 75% impervious surface in the area adjacent to the river. There are 56 piling groups, 49 pieces of LWD, including two large accumulations, and 14 occurrences of Japanese knotweed. Kellogg Island and the Turning Basin were two of the areas that had little or no armoring and were higher in habitat quality.

3.2.5. Marine Nearshore

This section focuses on current aquatic and riparian habitat conditions in the Marine Nearshore subwatershed of WRIA 9. This information is summarized from the Marine Shoreline Inventory Report (Anchor Environmental 2004b) and the Reconnaissance Assessment of the State of the Nearshore Ecosystem (Williams et al. 2001). Additional information on the Marine Nearshore subwatershed can be found in Sections 1.4.5 (general overview) and 2.3.1.5 (historical habitat conditions).

In the Marine Shoreline Inventory, habitat attributes were selected based on their relevance to nearshore habitat function for juvenile salmonids and the ability to classify their conditions using existing data sources or existing photographs (Anchor 2004). The attributes mapped included: substrate, marsh habitat, aquaculture/shellfish harvest areas, energy, sedimentation (net shore drift), freshwater inputs, marine riparian vegetation (MRV), LWD, shoreline armoring, impervious surfaces, overwater structures and marinas, boat ramps, jetties, breakwaters and groins, and marine rails. Data sources were USGS 2002 orthophotos, Ecology 2000 aerial oblique photos, WDNR Shorezone Inventory (2001) information, and WDOH 2002 shellfish closure area information. Detail on the characterization of individual habitat attributes was presented by Anchor Environmental (2004b).

A total of 151 km (90.6 miles) of marine shoreline was inventoried. Approximately 59% of the MRV consisted of trees, 28% was grass/landscaped and 10% had no vegetation. There was marsh habitat along 8% of the shoreline, with 6% patchy dune grasses, and only 1.5% native high marsh habitat. Large woody debris (downed trees that appeared to be still attached at the roots and that lay across the intertidal zone) was present along 14.7% of the shoreline. Drift logs were present along 21% of the shoreline and no wood was present along 64% of the shoreline. Shoreline armoring was present along 63% of the

shoreline. There were 250 identified overwater structures, 122 boat ramps, and 142 jetties, groins, or breakwaters. Impervious surface coverage was high (greater than 75% within 200 feet of the waterline) and medium (10-75% within 200 feet) along 11.6% and 48% of the shoreline, respectively. The most dominant materials of the supratidal zone were riprap (15.5%) and till (14%), whereas for the intertidal zone, the most dominant material were sand (36%) and pebble overlying sand (10.6%).

Vashon/Maury Island and Federal Way had the greatest extent of MRV as trees with 73 and 69%, respectively. The greatest extent of shoreline armoring occurred in the WRIA 9 portion of Seattle (90%) and the least amount of armoring occurred in Federal Way (42%) and on Vashon/Maury Island (50%). Boat ramps were most common on Vashon with 58, followed by Seattle with 29. Overwater structures were most common on Vashon with 130, followed by Seattle with 78. Finally, jetties, groins and breakwaters were also most common on Vashon with 75 identified.

Information on selected nearshore habitat types, including eelgrass meadows, kelp forests, flats, tidal marshes, sub-estuaries, sand spits, beaches and backshores was presented in the State of Nearshore Report (Williams et al. 2001). Much of this information is summarized from the WDNR Shorezone database (2001).

More detailed habitat assessments are underway in WRIA 9, but the information will not be available until later in 2004. This includes information on bathymetric LIDAR, additional marine shoreline inventory work, and an inventory of beach feeding sources, erosion and accretion areas.

3.3. WATER QUANTITY CONDITIONS

Water quantity conditions, including instream flows, groundwater, habitat-forming flows, and out-of-stream water use affect the quality and quantity of habitat available to salmonids for different life stages. The Reconnaissance Assessment Report (Kerwin and Nelson 2000) has a summary chapter on hydrology. Work is ongoing as part of the Strategic Assessment to complete a more detailed water quantity assessment. This section describes findings to date and additional information that will be available in Fall 2004.

3.3.1. Existing Water Quantity Conditions

Several historical changes have combined to have a profound effect on the water quantity conditions in the Green/Duwamish watershed. These include the diversion of the White River in 1906 and the Cedar/Black River in 1913, the construction of the Tacoma Diversion dam in 1911, and construction of the Howard Hanson dam for flood control in 1962. In addition, there were extensive land use changes that converted forests to urban, industrial, agricultural and rural uses, as well as numerous smaller water diversions and groundwater withdrawals that have affected water quantity conditions throughout the watershed.).

The White and Cedar/Black River combined previously comprised approximately 70 percent of the total watershed acreage and contributed a commensurate amount of flow to the lower Green/Duwamish River. Diversion of the White River in particular reduced summer low flows because of the loss of glacial meltwater. Tacoma continuously diverts up to 113 cfs from the mainstem Green River to meet the needs of the rapidly expanding population of Tacoma and southern King County. This diversion constitutes approximately 12 percent of the average annual flow at Palmer, the point of diversion. As a result of construction of the HHD, floods greater than 12,000 cfs (formerly the two-year return interval event as recorded at the USGS gauge in Auburn) have been prevented, while the duration of moderate flows (3,000 to 5,000 cfs) has increased due to metered release of floodwaters stored behind the dam.

Urban development in the Duwamish, Lower and Middle Green subwatersheds has resulted in substantial increases in stormwater runoff from small tributary streams and subbasins. This in turn has contributed to larger and more frequent peak flows during the winter, and reduced recharge of shallow aquifers that formerly sustained flows during the late summer and fall. Water withdrawals and diversion of springs or other surface water sources also serve numerous cities and water districts in the Lower and Middle Green subwatersheds. Cumulatively, these withdrawals, together with exempt wells further reduce the water available to streams and the mainstem Green River.

3.3.2. Natural Flow Analysis Findings

An analysis of natural flow conditions, conducted as part of the Reconnaissance Assessment (Kerwin and Nelson 2000), revealed the following findings:

- *Flows less than 302 cfs occurred 49 percent more often and summertime means and annual minimum extremes were consistently longer.* Reduces spatial habitat for rearing, decreases water depth in riffles, glides and pools and may constrain upstream adult Chinook migration. Reduces water velocity, potentially constraining downstream juvenile movement. Shallower water can lead to higher temperatures where temperatures already can exceed salmon preferences in the Green River. May decrease wetted width of river available for spawning, forcing Chinook to spawn closer to the thalweg, where scour potential is generally greater. May create adult Chinook passage problems from mainstem into Newaukum Creek.
- *The annual minimum flow occurred two weeks earlier, in late August rather than mid-September. May affect timing of upstream adult migration.* May create warmer, more stressful instream conditions where temperatures already can exceed salmon preferences
- *Flood peaks were reduced, with no flood flows above 11,000 cfs at Palmer (compared to one day flows ranging up to 18,000+cfs without projects (and peak flows even higher) and exceeding 11,000 cfs in 1 out of every 6 years).* River has less ability to create new side channel habitat, reducing habitat for salmon as well as recruitment of gravel from the floodplain. River has less ability to maintain existing side channels. River has less ability to recruit wood into the channel, reducing overall habitat quality. River margin habitats are less dynamic and becoming artificially stable, reducing gravel recruitment from stream margin.
- *Durations of moderate flood flows (greater than 5925 cfs) were longer by 39 percent.* May increase frequency or duration of scour of river bed gravel. Effects are compounded as fewer side channels (where scour would be less) are being created so more of the population spawns in the mainstem.

3.3.3. Water Quantity Assessment

A preliminary assessment of current water quantity conditions was completed in early 2004 (Northwest Hydraulic Consultants 2004). The assessment contains an overview of existing studies and reports, the conceptual approach for a more detailed study, selected points for analysis and proposed analysis statistics. The selected points of analysis include seven locations on the mainstem (from RM 23.8 below the Mill Creek confluence to RM 70 above HHD) and six tributaries (Mill, Soos, Covington, Jenkins, Crisp, and Newaukum creeks).

The statistics to be analyzed for each point include current conditons 7-day low flows and mean monthly flows, including 50% and 90% exceedance values. The analysis will also assess cumulative consumptive extraction from major wells, springs, and surface water diversions, as well as impervious area. Analyses to be completed by fall 2004 include: (1) current conditions streamflows, (2) groundwater basin boundaries, (3) biological evaluation of low streamflow data, (4) basin development and land cover conditions, and (5) a basin water balance.

3.4. WATER QUALITY CONDITIONS

This sub-section provides an assessment of the water quality conditions in the Green/Duwamish watershed from existing water quality reports, including Part I of the Reconnaissance Assessment report (Kerwin and Nelson 2000), the Green/Duwamish Watershed Water Temperature Report (Taylor Associates and King County 2004), and the Green/Duwamish Watershed Water Quality Data Report 2001-2002 (Herrera et al. 2004). Water quality data were compared to Washington State water quality standards (WAC 173-201A), EPA water quality criteria and appropriate toxicity screening thresholds to assess potential for biological significance. Available aquatic insect data were also evaluated as a measure of the aquatic ecosystem condition of selected streams. There is also a brief summary of sediment quality issues.

The analysis for this report divides the Green/Duwamish basin into four subbasins on the mainstem (Upper, Middle and Lower Green River, and the Duwamish River). The state water quality standards classify the water bodies in this basin as follows: (1) Class B (fair) – Duwamish River; (2) Class A (good) – Lower and Middle Green River up to river mile (RM) 42.3, Crisp, Newaukum, Soos, and Mill creeks, and the Black River; and (3) Class AA (extraordinary) – Middle Green River, from RM 42.3 to the headwaters.

Numerous stream systems throughout the Green/Duwamish watershed are listed on the State's 1998 303(d) list of impaired water bodies. Section 303(d) of the Clean Water Act requires Washington State to identify those water bodies that do not meet water quality standards. The State is then responsible for prioritizing the list and developing Total Maximum Daily Loads (TMDLs) for every water body and pollutant on the list. Some segments are also listed for sediments and tissues, but they are beyond the scope of this report. In the Green/Duwamish watershed, water body segments have been listed for failing to meet water quality standards for one or more of the following parameters: fecal coliform, temperature, dissolved oxygen (DO), pH, ammonia, and metals (cadmium, chromium, copper, mercury, and zinc).

3.4.1. Water Temperature

The WRIA 9 Reconnaissance Assessment report (Kerwin and Nelson 2000) identified temperature as a possible or probable factor of decline in the Green/Duwamish basin, depending on the subwatershed or tributary. High water temperatures could be creating adverse habitat conditions for egg incubation, juvenile salmonid rearing, and blocking or delaying summer migration of adult summer steelhead and Chinook. As a result of the findings in this report and in support of the Green/Duwamish Water Quality Assessment, a temperature assessment was initiated in 2001 to evaluate temperature conditions throughout the Green-Duwamish watershed (Taylor and King County WLRD 2004).

All temperature conditions presented in Taylor and King County WLRD (2004) were based on data collected between July 2001 and September 2003 at 93 surface water monitoring stations (representing 86 discrete locations due to some overlap) distributed throughout the watershed. Continuous temperature data were collected by King County, City of Kent, Tacoma Public Utilities, and the University of Washington for various intervals during this study period.

The temperature needs of salmonids for various life stages, and relative temperature ranges where impairment to a specific life stage is impacting or potentially impacting is summarized in Table 3.1. The temperatures of greatest interest from a regulatory standpoint are the summer maximum temperatures that can pose some level of threat to salmonid migration in the Green/Duwamish watershed. For example, average temperatures in the range of 18-20°C may periodically pose impairment to salmon migration while temperatures in the range of 21-22°C may result in a temperature related blockage to migration. Additionally, average temperature values in the range of 24-25°C may result in lethality (Ecology, 2002)

Table 3.1. Summary of Temperature Ranges and Potential Impacts to Various Salmonid Life Stages (adapted from Ecology, 2002).

Life Stage	Impairment Temperature Range as Daily Average or Maximum	Potential Impacts
Prespawning	average >14-16°C	-Reduce egg and sperm health
Egg	average >8-10°C maximum >13-15°C	-Reduced survival and emergence of healthy fry
Fry	average >13-15°C maximum >17-19°C	-Reduced survival
Parr to smolts	average >12-13°C Daily average >15-16°C	-Reduce support for smoltification -Halting of development process altogether
Adult Migration	average >15°C and maximum >18-20°C average >21-22°C average >24-25°C Plumes >32-33°C	-Impairment of migration -Blockage of migration -Lethality if not acclimated -Instant lethality

The water quality criteria for temperature were developed around aquatic life uses specifically. The categories for aquatic life uses include char; salmon and trout spawning, core rearing and migration; salmon and trout spawning, non-core rearing and migration; salmon and trout rearing and migration only; non-andromous interior redband trout; and indigenous warm water species.

The water quality criteria for temperature were developed around aquatic life uses specifically, including char; salmon and trout spawning, core rearing and migration; salmon and trout spawning, non-core rearing and migration; salmon and trout rearing and migration only; non-andromous interior redband trout; and indigenous warm water species. The 2003 temperature criteria are based on the 7-day average of the daily maximum temperature (7-DADMax). The 7-DADMax is the arithmetic average of seven consecutive measures of daily maximum temperatures. Surface water temperature criteria are summarized in Table 3.2 for the six river sections in the Green/Duwamish River system and associated use designations defined in WAC 173-201A-600, 2003.

3.4.1.1. Summary Results of Temperature Assessment

Taylor and King County WLRD (2004) provided a detailed breakdown by subwatershed (mainstem and respective tributaries) of temperature conditions for the 86 monitoring locations. Information was presented on the total days temperature standards were exceeded and the average number of degrees above standards. To assess thermal protection of ecological use of these surface waters as habitat, particularly for salmonid migration, a general review of Ecology's (2002) guidance was used to establish the following temperature thresholds of suitability:

- Less than 18°C .....no impairment of migration
- 18°C to 21°C .....potential impairment of migration
- 21°C to 23°C .....potential blockage of migration
- greater than 23°C.....potential lethality

Table 3.1. Applicable Temperature Criteria per Location and Use Designation for Char, Salmon, and Trout (adapted from WAC 173-201A, 2003, Table 200 and 602).

River	Location	Begin RM	End RM	Use designation	7-DADMax (°C)
Duwamish	Mouth to Black River	0	11	Salmon/trout migration and rearing	
				migration	17.5
				rearing	17.5
Green	Black River to Flaming Geyser State Park	11	42.3	Salmon/trout spawning, non-core rearing, and migration	
				migration	17.5
				non-core rearing	17.5
				spawning	13
				incubation [a]	13
Green	Flaming Geyser State Park to RM 59.1	42.3	59.1	Salmon/trout spawning, core rearing, and migration	
				migration	16
				core rearing	16
				spawning	13
				incubation [a]	13
Green	RM 59.1 to Green River Sunday Creek Confluence	59.1	RM-84.15	Salmon/trout spawning, core rearing, and migration	
				migration	16
				core rearing	16
				spawning	13
				incubation [a]	13
Green	Green River and Sunday Creek: all waters	Sunday Creek RM-84.15	headwaters	Char	
				migration	12
				rearing	12
	Smay Creek and West Fork Smay Creek: all waters	Smay Creek RM-75.3	headwaters	spawning	9
				incubation	9

[a] salmon and trout incubation covers all months of the year because salmon incubate fall through spring and trout spring through summer.

The following represent the key findings of the temperature assessment:

- All 17 mainstem locations exceeded the associated 2003 State water quality temperature standards for 10 or more days during the 2001, 2002, and/or 2003 water years, with an average degrees above the standard ranging from 0.4 to 3.5°C.
- Based on all stations, the maximum number of days the 2003 temperature standard was exceeded ranged from 85 to 130 days, depending on the water year. The maximum number of degrees the temperature standard was exceeded ranged from 4.2°C to 5.6°C. Average temperature exceedances ranged from 1.1°C to 1.7°C.
- Temperature data for 52 of the 86 monitoring stations violated the 2003 State temperature standard applicable to the subbasins on some or frequent occasions.
- Station tm-7 (Meridian Valley Creek) had the highest temperature exceedance with an average exceedance temperature of 23.1°C which has potential for lethality for salmonids. Stations CO1 (Covington Creek) and GRT02 (Springbrook Creek) had average exceedance temperatures of 21.5°C and 21.4°C, respectively, which have the potential for blockage to migration.
- An additional 29 stations had average exceedance temperatures between 18 and 21°C (potential for impairment), with four sites greater than 20°C: tm-2 (Lake Meridian outlet), TPU_479 (North Fork Green River), and GRT31 (Duwamish River at North Wind Weir), and GRT22 (Green River at Van Doren Landing).

Adult migration is a key life history stage affected by current temperature exceedances. Exceedances during adult migration may also indicate inadequate early fall cooling required to support adequate spawning, incubation, and rearing temperatures. Coho and steelhead subyearlings and steelhead yearlings that remain in freshwater throughout the summer after emergence are another key life stage affected by temperature exceedances.

Efforts to reduce surface water temperatures should be focused on areas most likely to benefit ESA listed fish species (e.g., Puget Sound ESU Chinook salmon). Areas specifically used by Chinook for migration may be of particular importance. Any sites with exceedances that overlap with Chinook distribution should be targeted for temperature reduction measures. Site-specific recommendations will require more fieldwork to assess local conditions and the potential for protection or acquisition of riparian areas, revegetation, restoration, and local management of water diversions or withdrawals.

3.4.2. Other Water Quality Parameters

The WRIA 9 Reconnaissance Assessment report (Kerwin and Nelson 2000) also identified dissolved oxygen as a possible or probable factor of decline, and total suspended solids (TSS) and metals as possible factors of decline in the Green/Duwamish basin, depending on the subwatershed or tributary. As a result of the findings in this report and in support of the Green/Duwamish Water Quality Assessment, a water quality data monitoring effort was carried out from 2001-2003 to further investigate water quality conditions in the Green/Duwamish watershed (Herrera et al. 2004).

Water quality monitoring was conducted according to a sampling and analysis plan (King County 2002), and involved collecting water samples at 18 sites located in the Lower and Middle Green and Duwamish subwatersheds. Two sites were located on the mainstem of the Green River (downstream of Tacoma Diversion Dam and at Fort Dent), five sites were located near the mouths of major tributary streams including Springbrook Creek, Black River, Mill Creek, Soos Creek, and Newaukum Creek. The remaining 11 sites were located on tributaries representing different land uses including forest (three

sites), agriculture (two sites), low-medium development (four sites), and high development (two sites). (King County 2002). Samples were collected during storm and baseflow conditions.

Numerous waterbodies in the Green/Duwamish watershed are included on the State's 1998 303(d) list, a list of waterbodies considered impaired (see Table 3.3). As part of the TMDL process, Ecology proposes to begin water clean-up planning in 2004 for the Green and Duwamish Rivers; and Big Soos, Newaukum, Springbrook and Mill (Hill) creeks (Ecology 2003).

Table 3.3. Water bodies monitored for the Green/Duwamish watershed water quality assessment identified on Washington state's 1998 303(d) list.

Water Body	Listed Parameter(s)[a]
Lower Green River (RM 11.0 to 32.0)	Temperature, fecal coliform bacteria, chromium, and mercury
Middle Green River (RM 32.0 to 64.5)	Temperature and fecal coliform bacteria
Springbrook Creek	Temperature, dissolved oxygen, fecal coliform bacteria, cadmium, chromium, copper, mercury, and zinc
Mill (Hill) Creek	Temperature, dissolved oxygen, and fecal coliform bacteria.
Soos Creek, Soosette Creek	Temperature, dissolved oxygen, and fecal coliform bacteria
Newaukum Creek	Dissolved oxygen, fecal coliform bacteria, and ammonia nitrogen
Crisp Creek	Fecal coliform bacteria

Source: King County 2000 and Ecology 1998.

[a] Table shows listings for water quality parameters not meeting applicable standards, but does not include sediment and tissue parameters.

3.4.2.1. Dissolved Oxygen Conditions

Dissolved oxygen (DO) is one of the most important water quality parameters for salmonids and other aquatic life. Washington state surface water standards require that DO concentrations exceed 9.5 mg/L in freshwaters designated for core salmonid rearing and 8.0 mg/L in freshwaters designated for noncore salmonid rearing (WAC 173-201A). Dissolved oxygen is a 303(d) listed parameter for each of the four major streams, but not for the upper Green River site (RM 63.8) or the lower Green River site (RM 11.9).

Summary statistics for DO concentrations during base and storm flow are presented in Herrera et al. (2004). Among all sites, DO concentrations ranged from 3.0 to 13.7 mg/L during baseflow and from 1.5 to 14.3 mg/L during storm flow. Between the two Green River sites (TDD, Fort Dent), DO concentrations showed a significant decreasing trend downstream. Median DO concentrations at the lower Green River site were approximately 2 to 3 mg/L lower during both base and storm flow relative to those at the upper Green River site. Only one of 14 samples from the lower Green River site exhibited a DO concentration (7.3 mg/L) that did not meet the state water quality standard, while all 17 measurements for the upper Green River site met the standard.

Among the four major stream sites (Mill, Newaukum, Soos, Springbrook), the DO standard was exceeded with the greatest frequency (43 to 100 percent of collected samples) in Springbrook Creek. In Mill Creek, the standard was exceeded in 12.5 percent of the base flow samples and 50 percent of the storm flow samples. The DO standard was never exceeded at Soos Creek and Newaukum Creek, although few samples were collected during summer base flow when the lowest DO concentrations would be expected.

Among the 11 tributary sites, median DO concentrations were lowest during base flow at the Mill Creek (Springbrook) tributary (5.8 mg/L at site draining high density development) and were lowest during storm flow at the Newaukum tributary at SE 424th (7.6 mg/L at site draining agriculture). Tributary sites not meeting the DO standard include Mill (Springbrook) tributary (71 and 25 percent exceedance during base and storm flow, respectively), Soosette Creek (25 percent exceedance during base flow), and three Newaukum Creek tributaries (20 to 60 percent exceedance during base or storm flows). Minimum dissolved oxygen levels observed at these sites ranged from 3.0 to 6.9 mg/L during base flow conditions and 1.5 to 7.3 mg/L during storm conditions.

For most salmonid life stages (juvenile rearing and migration and adult migration), slight, moderate, and severe production impairment occur at 6 mg/L, 5 mg/L, and 4 mg/L, respectively (U.S. EPA 1986). Acute mortality occurs at 3 mg/L. The minimum values observed at four sites during baseflow (Springbrook Creek, Black River, Mill Creek tributary to Springbrook, and Soosette Creek) and one site during storm flow (Newaukum Creek tributary) were 4 mg/L or below, leading to potential severe impairment to salmonids, if present.

3.4.2.2. Total Suspended Solids

Total suspended solids (TSS) is a measurement of the solids material in water that are retained on a standard glass-fiber filter. Suspended solids, especially the finer fractions, reduce light penetration in water and can have a smothering effect on fish spawning and benthic biota. Suspended solids are also closely associated with other pollutants such as nutrients, bacteria, metals, and organic compounds (Herrera et al. 2004). According to Kerwin and Nelson (2000), TSS is a possible factor of decline in the Lower Green and Duwamish rivers, and the Mill Creek and Springbrook Creek subbasins.

Monitoring in 2001-02 at the 18 sites resulted in base flow TSS concentrations that ranged from 0.5 mg/L to 62.2 mg/L, and storm flow TSS concentrations that ranged from 0.5 to 627 mg/L. During base flow, median TSS concentrations were 1.5 and 4.1 mg/L at the upper (RM 63.8) and lower (RM 11.9) Green River sites, respectively. There were no significant differences between these two sites during storm flow. At the four major stream sites, median storm flow TSS concentrations ranged from 7.5 mg/L at Soos Creek to 27.0 mg/L at Springbrook Creek. For the tributaries, the Mill Creek tributary to Springbrook had the highest median TSS concentration of all the sites during both base flow (6.6 mg/L) and storm flow (31.5 mg/L). Hamm Creek had the maximum storm flow TSS concentration (627 mg/L) among all sites.

Sub-lethal effects could be expected from exposure to 31 mg/L for a period of greater than three to seven hours, or from a 215 mg/L exposure over a period greater than one hour (Newcombe and Jensen 1996). Some of the sites noted above approached or exceeded these thresholds on some occasions.

3.4.2.3. Metals and Organics

Metals were identified as a possible factor of decline in the Lower Green and Duwamish rivers, and Springbrook Creek subbasin by Kerwin and Nelson (2000). In fish, for metal exposure concentrations that produce acute effects, gills are the principal site of toxicity (Evans 1987, Wood 1992). Metals bind to anionic sites on the gills and disrupt gill transport functions. If a metal cannot bind to the site of uptake, it will not be acutely toxic (Bergman and Dorward-King 1997).

Generally, metals were found to be below acute and chronic standards for most sites for most metals, with the following exceptions. On at least one occasion at all sites, total aluminum concentrations exceeded either the U.S. EPA chronic criterion during base flow or the acute criterion during storm flow. State criteria for dissolved copper were not met for one base flow sample from Mill (Springbrook) tributary and one storm flow sample from Newaukum tributary at 236th SE. State criteria for dissolved zinc were not met for one base flow sample from Mill (Springbrook) tributary and one storm flow sample from Green

tributary at Lea Hill (A330). Finally, the acute criterion for dissolved mercury was not exceeded in any of the samples, but the chronic criterion for total mercury was slightly exceeded in one base flow sample from the lower Green River and Mill (Springbrook) tributary. These collective results for the sites monitored indicate that metal concentrations are not a concern on most occasions.

An extensive set of priority organic compounds was monitored at the 18 sites during 2001-02 (Herrera et al. 2004). This included halogenated hydrocarbons, phenols, phthalates, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenols (PCBs), miscellaneous semivolatile organics, chlorinated and organophosphorus pesticides, and chlorinated herbicides.

Halogenated hydrocarbons and PCBs were not detected at any river or major stream site during base or storm flow sampling. Phenols were detected at Springbrook Creek, Upper Green River, Black River, Mill Creek, and Newaukum Creek. PAHs were detected at Lower Green River (RM 11.9), Black River, and Springbrook Creek. Caffeine was detected at all river and major stream sites except the Upper Green River (RM 63.8). The herbicide 2,4-D was detected in two samples from Springbrook Creek and the herbicide dichlorprop was detected in one sample from Newaukum Creek.

3.4.2.4. Aquatic Macroinvertebrate Conditions

Limited benthic macroinvertebrate data were available for assessment as part of the Reconnaissance Report (Kerwin and Nelson 2000). The benthic index of biotic integrity (B-IBI) is a common index used to assess overall community health (Fore et al. 1997) based on 10 macroinvertebrate metrics. The range of B-IBI scores is from 10 to 50, with a score of 46-50 considered excellent, 38-44 good, 28-36 fair, 18-26 poor and 10-16 very poor. Monitoring of macroinvertebrates in the Soos Creek basin (1995-98) found highly variable conditions. Five of eight stations monitored had B-IBI scores in the fair range, two were in the poor range and one station was in the very poor range. Seven stations monitored in 1999, located throughout the mainstem of the Green River all had B-IBI scores in the fair range. Mill (Kent) and Meridian Valley creeks had B-IBI scores in the very poor range.

Because of the limited data set available, King County initiated a study in 2002 to examine benthic macroinvertebrate communities across a broader geographic area in the Green/Duwamish and greater Lake Washington watersheds (EVS Consultants 2004). Monitoring occurred at 70 stations in 10 sub-basins of the Green/Duwamish. Between 3 and 11 sites were monitored in the individual sub-basins. Mean sub-basin B-IBI scores ranged from a high of 35.3 in the Deep/Coal sub-basin to a low of 14.8 in the Duwamish sub-basin. Three sub-basins (Deep/Coal, Newaukum, and Middle Green) had mean scores above 30. Individual B-IBI scores ranged from a low of 10 at three sites (one each in the Duwamish, Black River, and Lower Green sub-basins) to a high of 44 at a site in the Deep/Coal sub-basin. Five sites had scores in the good range (38-44), two in the Middle Green, and one each in the Deep/Coal, Soos, and Newaukum sub-basins.

In general, the B-IBI score of a given site is closely correlated with the land-use practices within the watershed, whether measured by percent impervious area or proportion of the watershed occupied by different types of land use (EVS Consultants 2004). The B-IBI scores were also correlated with changes in water quality. As mean conductivity, alkalinity, turbidity, TSS, total phosphorus, total zinc and copper increase, the B-IBI scores decrease. Finally, the B-IBI scores were significantly positively correlated with all four habitat variables. B-IBI scores increased with increasing dominant and sub-dominant substrate particle size, and left and right bank riparian tree density. A second year of data from the year 2003 will be available in Fall 2004.

3.4.3. Sediment Quality Conditions in the Duwamish River

A number of investigations within the Duwamish River have documented sediment contamination with PCBs, PAHs, phthalates, inorganics, and organotins (EPA 2003). In 1997, the natural resource trustees for the Duwamish River initiated an investigation to evaluate the extent and severity of PCB and polychlorinated terphenyl contamination in the sediments of the waterway. The trustees collected 328 sediment samples within the waterway. The analytical results for this study were compared to Washington State sediment quality standards. The major findings indicated that almost 71 of the 350 acres sampled, or just under 20 percent of the waterway, were estimated to have PCB levels that exceed the state standards.

A recent report by Windward Environmental (2004) presented results of a study of whole-body tissue and stomach content samples from wild and hatchery juvenile Chinook salmon in the Lower and Middle Duwamish Waterway (LDW/MDW). Whole body tissue samples were analyzed for PCBs, organochlorine pesticides, and tributyltin (TBT). Analyses were also performed on Chinook captured in the Green River upstream of LDW and from the Soos Creek Hatchery.

3.5. SALMONID POPULATION CONDITIONS

This sub-section contains information about current salmonid populations in WRIA 9, including a summary of Chinook information for the four viable salmonid population (VSP) parameters and more limited information on other salmonid species. This information is summarized from King County WLR (2004b) and Kerwin and Nelson (2000).

3.5.1. Population Conditions

This section includes information on Chinook population conditions for the four VSP parameters.

3.5.1.1. Abundance

Three approaches that estimated current abundance (and productivity) of Green River Chinook were summarized by King County WLR (2004b). The first approach was based on estimates from the WDFW terminal run reconstruction (RR) of natural Chinook salmon. Abundance estimates from this approach were shown by Nelson et al. (2004) and the methodology was briefly described by Weitkamp and Ruggrone (2000). This approach provides terminal run size of hatchery versus natural Chinook salmon, but it considers hatchery fish spawning in the river as natural salmon and natural salmon spawned at the hatchery as hatchery salmon. The second approach is summarized in Weitkamp and Ruggerone (2000), where they expanded upon the terminal RR approach by incorporating sport harvests and harvests that occurred outside Puget Sound. This expansion was based on analyses of coded-wire-tagged Chinook salmon. However, like the terminal RR, this approach classified hatchery strays to the spawning ground as natural salmon because reliable estimates of hatchery strays were not available.

The third approach, completed more recently by the TRT (unpublished data) involved reconstructing the Chinook salmon run after excluding the contribution of hatchery strays to the spawning ground and including natural origin fish that returned to the hatchery. The TRT approach included salmon captured in sport and non-terminal fisheries and was based on CWT data. Each of the three methods is valid, but it is important to understand what the different approaches include and exclude. The TRT approach attempts to provide the most realistic evaluation of natural Chinook production and productivity, but it is also the most data intensive, and thus it is the most prone to measurement error, especially when examining year-to-year runs size or productivity. Values from the three approaches are described below. It is important to recognize that none of these methods currently utilize the recent spawning escapement analyses by

WDFW that suggests that the traditional redd count spawning escapement method undercounted escapement by approximately 50% based on a recent three year mark-recapture study (Hahn and Cropp 2003; T. Cropp, pers. comm.).

The population estimates from the different sources vary and will continue to be improved as new methods to determine escapement estimates are furthered refined. It is also important to note that there are inherent uncertainties in these population estimates. However, by comparing these estimates (Table 3.4), it is possible to begin to formulate a conception of what the current population looks like. In Table 3.4, the estimates by Puget Sound TRT and Weitkamp and Ruggerone (2000) are total run size, which includes both escapement and all harvest; the mean abundance estimates vary by approximately 25 percent (3,500 fish). In conclusion, estimates of current natural Chinook population abundance vary according to the methods and assumptions employed.

Table 3.4. Means of naturally spawning Chinook population estimates from varying sources. Time frames and what each data set includes is described.

Author	Includes	Years of Estimate	Range	Mean
Puget Sound Chinook Technical Recovery Team unpublished data	natural-origin run size defined as escapement plus all harvest; excludes hatchery strays	1971-2000	729 - 29,647	11,206
Weitkamp and Ruggerone (2000)	naturally spawning component defined as escapement plus all harvest; includes hatchery strays	1968-1998	4,262 - 31,355	14,700
J. Packer, WDFW, via Nelson et al. (2004)	estimate includes escapement and commercial and Indian harvest only within Puget Sound; includes hatchery strays	1968-2002	3,866 - ~15,589	9,148

3.5.1.2. Productivity

Using only adult spawners to calculate productivity (recruits per spawner) of natural origin Chinook salmon, the Puget Sound TRT (unpublished data) estimated adult recruits per adult spawner (R/S) for Green River natural Chinook for the period 1971-1998 to average 2.32 (Table 3.5). By using total spawners (adults and jacks), productivity results in slightly different numbers (a mean of 2.35).

Table 3.5. Adult recruits per adult spawner (R/S) from 1971 to 1998, broken into decades for Green River Chinook. These figures include a natural spawner adjustment for hatchery effectiveness of 1.

Statistic	1971 to 1998
Count	28
Median	1.20
Mean	2.32
Standard Deviation	2.86
Coefficient Variation	123%
Minimum	0.00
Maximum	11.07

The recruitment curve presented in King County WLR (Figure 4, 2004b after Weitkamp and Ruggerone 2000) shows considerable variability in adult returns from escapements between 1,800 and 11,500 fish. This dataset includes hatchery fish that strayed to the spawning grounds. The authors point out that the escapement level leading to maximum harvests was approximately 5,000 fish.

One of the greatest influences on Chinook productivity and our attempts to measure productivity in the Green/Duwamish system is the presence and affects of the hatcheries. In the VSP guidance document, McElhany et al. (2000) states a viable salmon population that includes naturally spawning hatchery fish should exhibit sufficient productivity from naturally produced spawners (i.e. not hatchery origin) to maintain population abundance at or above viability thresholds in the absence of a hatchery subsidy. The population should not exhibit a trend of proportionally increasing contributions from naturally spawning hatchery fish. In the Green River, the contribution of hatchery fish to spawning ground escapements has likely increased in recent years due to reduced harvest rates on hatchery and natural origin Chinook salmon and continued high production of hatchery salmon.

Other measures of productivity are also summarized in King County WLR (2004b) including adult to fry/smolt productivity that was estimated by Seiler et al. (2002) in a report using 2000 screw trap data. The results of this one-year study indicate an estimated egg-to-migrant survival of 7.3 percent. A recent study indicates that Green River natural Chinook fingerlings were similar to mean size of subyearling Chinook salmon migrating from other watersheds (Nelson et al. 2004). In 2003 growth of natural juveniles appeared to be suppressed during the time juvenile hatchery fish are being released into the system (Nelson et al. 2004, Ruggerone and Jeanes 2004). The duration of impact appeared to be approximately three weeks. Additionally, mark and recapture of natural Chinook salmon if off-channels within the Duwamish estuary indicated residence time of natural Chinook salmon declined significantly immediately after release of approximately 3 million hatchery Chinook salmon. These data may have implications for survival and productivity, but only one year of comprehensive data have been collected.

3.5.1.3. Spatial Structure

Spawning records have been collected for the Green River for the past 60 years and were used as the data source to describe the current spatial distribution of spawning (WDFW, undated; Malcom, 2002, Martin et al. 2004). Malcom (2002) and Martin et al. (2004) both used data from Washington Department of Fisheries and Wildlife spawner database. Green River summer/fall Chinook salmon spawning surveys were completed between RM 25.4 and 61.1.

Table 3.6. Relative distribution of Chinook redds (% of total) in the major basin of Green River 1997-2002. 1997-1998 data from Malcom (2000). 1999–2002 data from Martin et al. (2004). Both sources used WDFW spawner database. River Miles according to William et al. (1975).

Segment	RM Lower	RM Upper	Percent of survey length	1997 (%)	1998 (%)	1999 (%)	2000 (%)	2001 (%)	2002 (%)	Mean (%)
Lower Green	25.4	33.8	27.7	9.9	19.6	30.0	17.6	8.4	21.4	17.8
Lower Middle Green	33.8	43	26.0	40.4	46.9	48.8	40.9	40.2	49.7	44.5
Upper Middle Green	43.0	60.8	50.3	49.7	33.5	21.1	41.5	51.5	28.9	37.7

In the past, field surveys in the Green River used more general reaches that have progressively become more refined. Prior to 1999, the survey data was grouped together into three segments: Lower Green (RM 25.4 to 33.8), Lower Middle Green (RM 33.8 to 43), and Upper Middle Green (RM 43 to 60.8) (Table 3.6)

When examined at a broad scale, approximately 80 percent of the Chinook redds occur upstream of Soos Creek in the Middle Green River Subwatershed. Relative spawning distribution varied considerably by year for the Lower Green and Upper Middle Green segments (Table 6). On average, approximately 17.8 percent of the spawning occur in the Lower Green (8.4 miles).

Beginning in the years 1999 to 2002, survey methodologies allowed more data on the actual distribution and density of Chinook redds to be available. As a result, it is possible to identify the survey sections of the river with greatest densities of redds. Since survey lengths differ and total number of spawning Chinook varied over time, Martin et al. (2004) determined the standardized redd density (SRD) for each survey segment for a given year. This provides a relative index of abundance for the delineation and comparison of redd spatial patterns. The SRD was computed by dividing the redd density (i.e., redds per mile) for each survey segment by the total number of redds in all segments for a given year. The SRD was classified into low, medium, high, and very high to assist with displaying these data and determining spatial patterns in spawning distribution (Figure 3.1).

The spatial structure of juvenile Chinook salmon in the Green/Duwamish watershed is continuing to emerge. Although studies have been conducted as far back as 1952 (Heg 1952), no distinction was made between hatchery and natural fish. It is important to recognize this distinction because of the different behavioral patterns between them. These behavioral patterns produce a very different understanding of the spatial distribution of juveniles and the spatial structure of habitats.

Studies have been underway since 2001 by King County that have been providing new findings on juvenile rearing distribution in freshwater habitats (Nelson et al. 2004) and the nearshore (Brennan et al. 2004). The U.S. Army Corps of Engineers has also been funding an on-going study (1999/2000) of juvenile salmonid use in the lateral stream habitats of the Middle Green River (R2 Consultants 2001). Since examples of spatial analysis of juvenile rearing distribution are limited, recent findings for assessing juvenile rearing distribution are presented together with information on riverine characteristics to identify the areas that are believed to be preferred habitat by juveniles (King County WLR 2004b). It should be recognized that further research is still needed to continue to fill in data gaps and to broaden our knowledge on this subject.

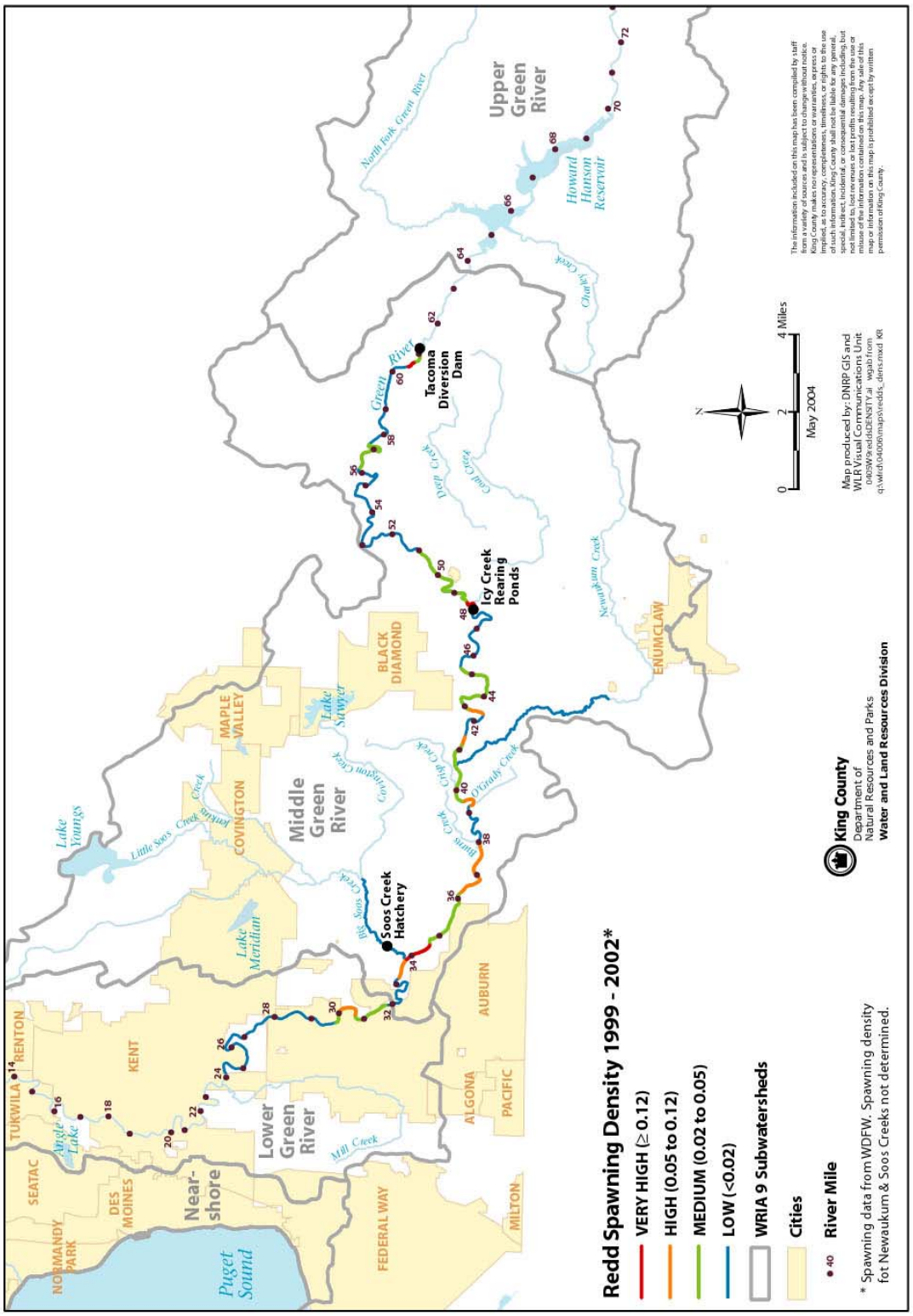


Figure 3.1. Current Spawning Distribution of Green River Summer/Fall Chinook

Nelson et al. (2004) found that catches of natural subyearlings Chinook (fry and fingerlings) were consistently higher in the Duwamish River estuary transition zone (RM 5.5 to RM 7) compared with rates in the lower river (RM 13) and lower Duwamish estuary (RM 0, RM 1) for years 2002 and 2003. These data suggest that juvenile salmon aggregate and reside at RM 5.5-7 for longer periods compared with other sites. The transition zone is thought to provide a significant habitat patch for juvenile rearing in the estuary because it provides a shallow, slow-moving water area within the mainstem channel, where juveniles can acclimate to increase salinity. The geographic extent of the transition zone is under investigation to determine its upper and lower boundaries.

It is believed that the Lower Green River currently functions primarily as a migration corridor for juvenile salmonids because of the lack of shallow, slow-moving water refuge, except in low flow years. A recent study by Nelson et al. (2004) provides some initial observations on juvenile use of the lower river. In 2001, river flows were relatively low and catch rates of subyearling Chinook salmon at RM 13 tended to be higher than those in 2002 and 2003 when flows were considerably higher. Data suggest that the combination of high flows and the lack of refuges have reduced the capacity of the lower river to support juvenile salmon. This may have a greater effect on fry migrants that seek low velocity habitats. Fry migrants are much more abundant when leaving the middle Green River compared with fingerlings that migrate later during spring. Additional research is needed to further evaluate rearing in the Lower Green River.

The Middle Green River is known to provide juvenile salmonid rearing habitat. Before the Chinook migrate from the Middle Green they have been observed primarily using the shallow mainstem margins with low water velocities and cover until late March to early April (Jeanes and Hilgert 2001). Then the Chinook were observed to use deeper areas in the river such as the thalweg, scour pools and in mats of large woody debris.

The marine nearshore provides valuable habitat for juvenile salmonids and is important when discussing spatial distribution of juvenile rearing habitat. Unfortunately, research on this subject is limited for WRIA 9 nearshore as well as all of Puget Sound. Juvenile Chinook use the marine nearshore for extensive periods of time, and are probably the most nearshore dependent salmonid in WRIA 9 (Brennan et al. 2004). The use of the nearshore habitat appears to be dependent on size relative to water depth with smaller subyearlings using shallow intertidal habitats and yearlings being more prevalent in deeper channel areas (Bottom et al. 1984; McCabe et al. 1986). Despite extensive marine nearshore habitat modifications, the WRIA 9 marine nearshore is known to provide rearing habitat for at least ten Puget Sound hatchery stocks (Brennan et al. 2004). Since there is no method to easily determine origin of wild juvenile Chinook salmon, it is not known how many or which stocks are using WRIA 9 marine nearshore, but it is likely that there are similarities between the distribution of hatchery and wild populations.

3.5.1.4. Diversity

Currently, only ocean-type (summer/fall stock) Chinook salmon are found in the Green/Duwamish watershed. Multiple factors probably contributed to the loss of the stream-type Chinook from the watershed. Perhaps the two most significant factors were the elimination of the headwater habitat that resulted from the re-routing of the White River in 1906 and the construction of the Tacoma Diversion Dam in 1911 that blocked all upstream migration. Although spring Chinook salmon are considered to be extinct (Nehlsen et al., 1991; WDFW et al., 1993; Puget Sound TRT, 2003), tribal managers still dispute whether this is true. Evidence of early September spawning of Chinook in the higher reaches of the mainstem Green River could be indicative of a few remaining individuals of the Green/Duwamish spring population (WDFW et al., 1993); however, they could also be early spawning fall Chinook.

The most common age of maturity for Green/Duwamish summer/fall Chinook salmon is four years (62 percent), followed by three years (26 percent) and five years (11 percent) with just 1 percent being either

two year olds or older than six years of age (Myers et al., 1998). Green/Duwamish summer/fall Chinook salmon currently begin to enter the Duwamish River in mid-June, peaking in August (Ruggerone and Weitkamp, 2004). The mean peak return timing at the Soos Creek Hatchery is October 4th (1960 to 1997).

As part of the WRIA 9 Chinook Salmon Research Framework, a Conceptual Model of Natural Green River Chinook Salmon was developed by Ruggerone et al. (2004). This model is based on our current understanding of juvenile rearing patterns within Green/Duwamish watershed as well as our knowledge about other similar but less disturbed systems (See Ruggerone and Weitkamp 2004, Figure 3). The following classification, based on estimated body length and approximated residence time within rearing habitats, attempts to capture the diversity of juvenile life histories for Green River Chinook salmon.

- Fry that migrate soon (days to weeks) after emergence from the Middle Green River spawning grounds, then rear in the Lower Green and/or the Duwamish estuary (days) before entering Puget Sound *(marine-direct fry)*
- Fry that migrate soon (days to weeks) after emergence from the Middle Green River spawning grounds, then rear in the Duwamish Estuary (up to three months) before entering Puget Sound *(estuarine-reared fry)*
- Fry that migrate soon (days to weeks) after emergence from the Middle Green River spawning grounds, then rear in the Lower Green (weeks to months) and estuary (weeks) before entering Puget Sound *(lower river-reared fry)*
- Fingerlings that rear near the Middle Green River spawning grounds (one or two months) before migrating relatively quickly through the estuary to Puget Sound (days to weeks) *(marine-direct late migrant)*
- Yearlings that rear near the Middle Green River spawning grounds (for a year) before migrating relatively quickly through the Lower Green and/or the Duwamish Estuary (days to weeks) before entering Puget Sound *(yearling)*

Based on limited sampling, the most common life history trajectories in the Green/Duwamish River appear to be the *estuarine-reared fry* and *marine-direct late migrant*. These trajectories are based on the recent sampling of emigrating juveniles at RM 34, RM 13 and in the Duwamish estuary (Nelson et al. 2004, Ruggerone et al., 2004).

Mainly as a result of habitat modification in the Greater Duwamish watershed, the only remaining recognized independent population is the Green/Duwamish summer/fall Chinook (PSTRT, 2001). In the 1993 WDFW Salmonid Stock Inventory report, the Green/Duwamish summer/fall Chinook salmon was separated into two stocks: Green/Duwamish River Summer/Fall Chinook and Newaukum Creek Summer/Fall Chinook. As a result of genetic analysis of Soos Creek hatchery and Newaukum Creek natural spawners, the genetic basis for this distinction is not valid since there is no significant difference between these two populations (WDFW SASI, 2004). Genetic analysis of Green River mainstem natural spawners has not been conducted at this time.

3.5.2. Current Population Conditions for Other Salmonids

King County WLR (2004b) also summarized information on population conditions for other salmonids. Other salmonids present within the Green/Duwamish watershed include chum, coho, pink, sockeye, cutthroat trout, bull trout and steelhead. Information on population abundance and distribution data is available in the WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment Report (Kerwin and Nelson 2000). Nelson et al. (2004) and Brennan et al. (2004) also collected information on other salmonids as part of the juvenile survival studies and beach seining efforts.

3.5.2.1. Chum

The chum salmon that enter the Green River watershed are considered part of the South Puget Sound area chum stocks (Phelps et al. 1995). Two stocks are present in the Green River (WDFW and WWTIT 1994): Green River fall-run chum and Crisp Creek (also known as Keta Creek) fall-run chum. The origin of the Green River fall-run chum is an East Kitsap/wild remnant mix, while the Keta Creek fall-run stock originated from the Cowling Creek broodstock, whose origin is from Chico Creek in East Kitsap (Dorn 2000). Spawning information on the remnant mixed origin Green River stock is limited and no attempt was made in the Reconnaissance Report to provide escapement estimates.

The distribution of chum salmon in WRIA 9 was summarized in the fish distribution maps of the Reconnaissance Report (see Appendix, Part V). Chum have been observed on the Green River mainstem up to RM 56.3, in Newaukum Creek, in several smaller tributaries of the Middle Green River Subwatershed (Crisp Creek, Burns Creek, tributary 09.0098) and in Judd Creek on Vashon/Maury Island. The WDFW WRIA Catalog of Streams (Williams 1975) also notes chum presence in Big Soos Creek and in the mainstem up to the Tacoma diversion dam.

3.5.2.2. Coho Salmon

Coho salmon in the Green/Duwamish River basin are separated into two stocks (WDFW and WWTIT, 1994): Green/Duwamish and Newaukum Creek. Escapement estimates for the Green/Duwamish River stock from 1967 to 1998 averaged 3,816 and ranged from 700 to 12,500 (Kerwin and Nelson 2004). Newaukum Creek is a left-bank tributary that joins the mainstem Green River at RM 40.7. Spawning escapement index data estimates for this stock from 1960 to 1996 averaged 5,029 and ranged from 1,034 to 9,300. Of particular interest is the significant difference in spawn timing between these two stocks that might be indicative of genetic differences. Coho returning to the Green River typically spawn up to mid-November. Newaukum Creek coho appear to spawn into mid-January (WDFW and WWTIT 1992, WDFW Spawning Ground Survey Database). The naturally spawning coho population in the Green River basin is comprised of an unknown mixture of natural and hatchery origin fish. The magnitude of adult hatchery fish that contribute to the natural spawning population has not been determined. The spawning escapement estimates include hatchery strays, a fact that leads to overestimation of the "wild" coho run produced by naturally spawning parents.

Green/Duwamish River coho stocks typically enter freshwater from September to early December, but have been observed as early as late-July and as late as mid-February (MIT unpublished data). Spawning usually occurs between November and early February, but is sometimes as early as mid-October. Spawning typically occurs in tributary streams. Coho juveniles remain in the river for a full year after emergence, but during the summer after early rearing, low flows can lead to problems such as a physical reduction of available habitat, increased stranding, decreased dissolved oxygen, increased temperature, and increased predation.

The distribution of coho salmon in WRIA 9 was summarized in the fish distribution maps of the Reconnaissance Report (see Appendix, Part V). Coho salmon are the most broadly distributed salmon in WRIA 9. Coho have been observed on the mainstem up to the Green River headwaters (RM 90), including Sunday Creek. They are found in tributaries throughout the Newaukum Creek, Soos Creek, Mill Creek and Springbrook Creek subbasins. They are also present in Judd and Shinglemill creeks on Vashon/Maury Island, and Puget Sound direct tributaries on the mainland such as Longfellow, Miller, and Des Moines creeks. See Kerwin and Nelson (2000) for more information on coho distribution.

3.5.2.3. Pink Salmon

As recently as the mid-1990s, pink salmon were thought to be largely absent from the Green River watershed. No mention of a pink salmon stock in the Green River was made in SASSI (WDFW and WWTIT 1994). Williams et al. (1975) characterized Green River pink salmon as extinct from the basin. In the late 1990s, low numbers of pink salmon adults were observed in odd number years during spawning ground surveys in the mainstem Green River and a few tributaries (WDFW, 1999a).). In the fall of 2001, the number of pink salmon adults in the Green River rose dramatically to an estimated 20,000 fish, and in 2003, an estimated 300,000 adults spawned in the system. Observations of spawning adults have occurred primarily in odd numbered years, and the majority of fish that entered the Green in 2001 and 2003 were likely strays from the Snohomish and Puyallup river systems.

In 2000, 1,200 juvenile pink salmon were captured in a screw trap on the mainstem Green River at RM 34.5 (Seiler et al. 2002) indicating reproductive success from spawning through incubation to fry emergence. Juvenile pink salmon were also captured in the estuary in recent years (Nelson et al. 2004).

Adult pink salmon return at two years of age and typically begin to enter the Green River mainstem in August and spawn in September and October of odd numbered years. Pink salmon fry in the Green River basin emerge from redds around March and migrate downstream to the estuary within a month. After a limited rearing time in the estuary, pink salmon migrate to the ocean for a little over a year, until the next spawning cycle. Most pink salmon stocks in Washington State return to the rivers in odd years. The distribution of pink salmon in WRIA 9 was summarized in the fish distribution maps of the Reconnaissance Report (see Appendix, Part V). In odd-numbered years since the early 1990s, pink salmon adults, generally numbering less than 200 per year, were observed in the Green River mainstem below RM 42 and in the Newaukum Creek subbasin. In 2003, with record observed numbers of pink salmon, mainstem spawning was noted up to RM 60.6.

3.5.2.4. Bull Trout

The status for bull trout in the Green/Duwamish watershed is unknown (WDFW 1998). Information on the presence, abundance, distribution, utilization and life history of bull trout in the Green River basin is either unavailable or extremely limited (Kerwin and Nelson 2000). The USFWS (2004), in the Puget Sound Management Unit for the Bull Trout Recovery Plan, identified the Green River as foraging, migration, and overwintering habitat. Information on the historical observations of native char, Dolly Varden and bull trout dating from 1856 through the 1930s are presented in Kerwin and Nelson (2000).

Investigations (Watson and Toth 1994, Tacoma Water HCP 1999 Draft) have not provided any evidence of bull trout spawning in the Green River watershed; however, native char were captured as far upstream as RM 40 in the Green River (Watson and Toth 1994). Recreational anglers have reported sightings of native char in the lower Green River (Kerwin and Nelson 2000). Native char were not observed or captured upstream of Howard Hanson Dam as a part of surveys conducted by Plum Creek Timber Company (Watson and Toth, 1994), though it is important to note that observations were primarily during the summer months and the surveys were not specifically designed to look for bull trout.

Bull trout were reported in the lower mainstem Green/Duwamish River on several occasions. During a fish study conducted by the Port of Seattle, a single adult Dolly Varden was captured in the Duwamish River at RM 2.1 (Weitkamp 1980). In 1980, one bull trout/Dolly Varden was collected, downstream of RM 4.0, as part of a juvenile salmonid study in the Duwamish River (Weitkamp 1982). An adult bull trout was captured by the Muckleshoot Indian Tribal staff at approximately RM 5 during juvenile beach seining in 1994 (R. Malcom 1999). This fish was analyzed by the University of Washington and confirmed to be a bull trout. Finally, an adult bull trout was captured by Taylor Associates in 2002 in the Duwamish River. It is believed that these recently observed adult bull trout are not of Green/Duwamish

River basin origin, but foraging, migrating or overwintering in the Green/Duwamish River basin. More information on recent observations can be found in Section 5.

The distribution of bull trout in the Green/Duwamish watershed is not well known. Observation have been most common in the Duwamish estuary, but it appears bull trout use the Green River mainstem, perhaps as far upstream as the Middle Green River. It is also likely that foraging may occur in some tributaries.

3.5.2.5. Steelhead Trout

There are two Green/Duwamish River basin winter steelhead stocks characterized in SASSI (WDFW and WWTIT 1994): the native wild spawning population and the early timing hatchery stock. Population trends of Green River wild winter steelhead in the early 1990s began a steady decrease similar to those of many other regional stream systems. No escapement data for Green/Duwamish River basin origin winter steelhead stocks is available prior to 1978. From 1978 to 1998, escapement estimates ranged from approximately 960 to 2800 fish. SASSI (WDFW and WWTIT 1994) concluded that wild adult summer steelhead caught in the Green River basin are either strays from other systems, offspring of naturally spawning hatchery adults or are actually adult winter steelhead caught during the summer steelhead management period (May 1 to October 31). The current hatchery summer steelhead stock in the Green River Basin is a non-native (hatchery introduced) stock with origins from the Washougal and Skykomish Rivers. Hatchery summer steelhead have been released in the Green River since 1965. River entry occurs from April through October and spawning from mid –January through mid-March.

Naturally produced juvenile winter steelhead can either migrate to sea or remain in freshwater as a resident rainbow trout. The vast majority of juvenile steelhead smolt and migrate to saltwater. Green/Duwamish origin steelhead usually spend one to three years in freshwater (with the greatest proportion spending two years). Because of this, steelhead rely heavily on freshwater habitat and are present in streams all year long. The distribution of steelhead in WRIA 9 was summarized in the fish distribution maps of the Reconnaissance Report (see Appendix, Part V). Steelhead are widely distributed throughout WRIA 9. Steelhead have been observed on the mainstem up to the Green River headwaters (RM 90), and in the Sunday Creek headwaters. They are found in Newaukum Creek, Soos Creek and its larger tributaries, Mill Creek and Springbrook Creek. They are also present in Judd and Shinglemill creeks on Vashon/Maury Island. See Kerwin and Nelson (2000) for more information on steelhead distribution.

3.5.2.6. Coastal Cutthroat Trout

SaSI (WDFW and WWTIT 2000) identified a distinct stock of coastal cutthroat trout in the Green River Basin. Johnson et al (1999) in the NMFS status review of cutthroat trout includes the Green River Basin in the Puget Sound ESU. Assessing populations of coastal cutthroat trout in the Green River Basin is particularly difficult (Kerwin and Nelson 2000). NMFS found that the scarcity of information available made risk assessments extremely difficult for coastal cutthroat trout. In ..... (WDFW 2000), it was the conclusion of the editors that the stock status of Green River coastal cutthroat complex was unknown. The only data cited was limited electrofishing surveys conducted in Newaukum Creek.

Anadromous coastal cutthroat trout are found year-round in shallow water close to marine nearshore areas. Coastal cutthroat trout generally migrate from fresh water to marine nearshore areas in the spring at two to three years of age (Trotter 1989). Most anadromous cutthroat trout, having migrated in spring, return to their natal stream to spawn in the following year. Spawning may begin as early as December and continue through June, reaching a peak in February (Trotter 1989). The distribution of cutthroat trout in WRIA 9 was summarized in the fish distribution maps of the Reconnaissance Report (see Appendix, Part V). Cutthroat trout are the most widely distributed salmonid in WRIA 9. Cutthroat trout have been

observed on the mainstem up to the Green River headwaters (RM 93), and in major tributaries in the Upper Green River Subwatershed, including North Fork Green River, Sunday Creek, and Smay Creek. They are found in Newaukum Creek, Soos Creek, and its larger tributaries, Mill Creek and Springbrook Creek. They are also present on multiple small tributaries on Vashon/Maury Island, as well as Judd and Shinglemill creeks, and Puget Sound direct tributaries on the mainland, such as Longfellow, Miller, and Des Moines creeks. See Kerwin and Nelson (2000) for more information on cutthroat trout distribution.

SECTION 4 – COMPARISON OF HISTORICAL AND CURRENT SALMONID AQUATIC HABITAT CONDITIONS IN WRIA 9

4.1. INTRODUCTION

This section compares historical and current salmonid aquatic habitat conditions in WRIA 9. Specifically, it examines changes in the floodplain and the aquatic habitat including mainstem and tributary channels, and in-channel wood for the Upper, Middle, Lower Green and Duwamish subwatersheds. A change analysis for the entire Marine Nearshore Subwatershed is not feasible at this time due to time constraints and the lack of readily available data; however, Elliott Bay is examined to a limited extent. By examining how the river, floodplain, and estuary functioned historically, we can gain insight on how the Green River salmonid species adapted to their habitat and how historical habitat conditions supported a viable population in terms of abundance, productivity, diversity and distribution. Comparing historical habitat conditions to current habitat conditions will allow us to identify and quantify how the aquatic habitat has changed over time, providing clues on the current status of the Green River Chinook population. These findings will be used to develop conservation hypotheses, set necessary future habitat conditions targets, and guide habitat restoration efforts to support recovery and conservation of salmonids.

The Green River has undergone some dramatic change (White and Cedar diversions, HHD), but it has also undergone small incremental changes that have resulted in a homogenous system that functions quite different than a naturally dynamic river with habitat complexity, a requirement of the salmonids. The loss of complexity has likely had serious impacts on juvenile rearing and spawning habitat, and the overall viability of the Green River population.

For more detailed information, refer to: *Comparison of Historical and Current Salmonid Aquatic Habitat Conditions in WRIA 9* (King County, In Draft), *Historical and Current Habitat Conditions Analysis for the Upper Green River Basin* (King County 2004), and *Historical Aquatic Habitats in the Green and Duwamish River Valley* (Collins and Sheikh 2004).

4.2. METHODS

Geographic Information Systems (GIS) was used to perform the quantitative analysis of habitat change except for historical estimates for in-channel wood and pools.

4.2.1. Historical Baseline Information

The extent and complexity of the historical landscape cannot be fully known with absolute certainty. Attempts to quantify habitat types can result in misrepresentation of actual loss and ignore the value of historical reconstruction of landscapes. In the case of the Green-Duwamish Watershed, it is clear that significant habitat area loss has occurred in the Duwamish and Lower Green Subwatersheds, and Elliott Bay, and to a lesser extent in the Middle and Upper Green Subwatersheds. However, the ecological and biological processes that were lost and are required to create the habitat requirements of salmonids are less clear.

Historical habitat estimates in this report are based on historical reconstructions that used a variety of sources (e.g. General Land Office (GLO) Surveys, USGS Topographic Maps, Lidar). The estimates

should be used cautiously since the survey methods were limited, and map sources were either incomplete or varied in accuracy. Efforts were made to cross-reference sources; however, historical reconstructions will always be incomplete and subject to both known and unknown biases.

Section 2 summarizes the historical baseline information (Collins and Sheikh 2004; King County 2004) used in this analysis. Section 3.2 summarizes the current aquatic habitat conditions used for the comparison.

4.2.2. Assessment Reaches

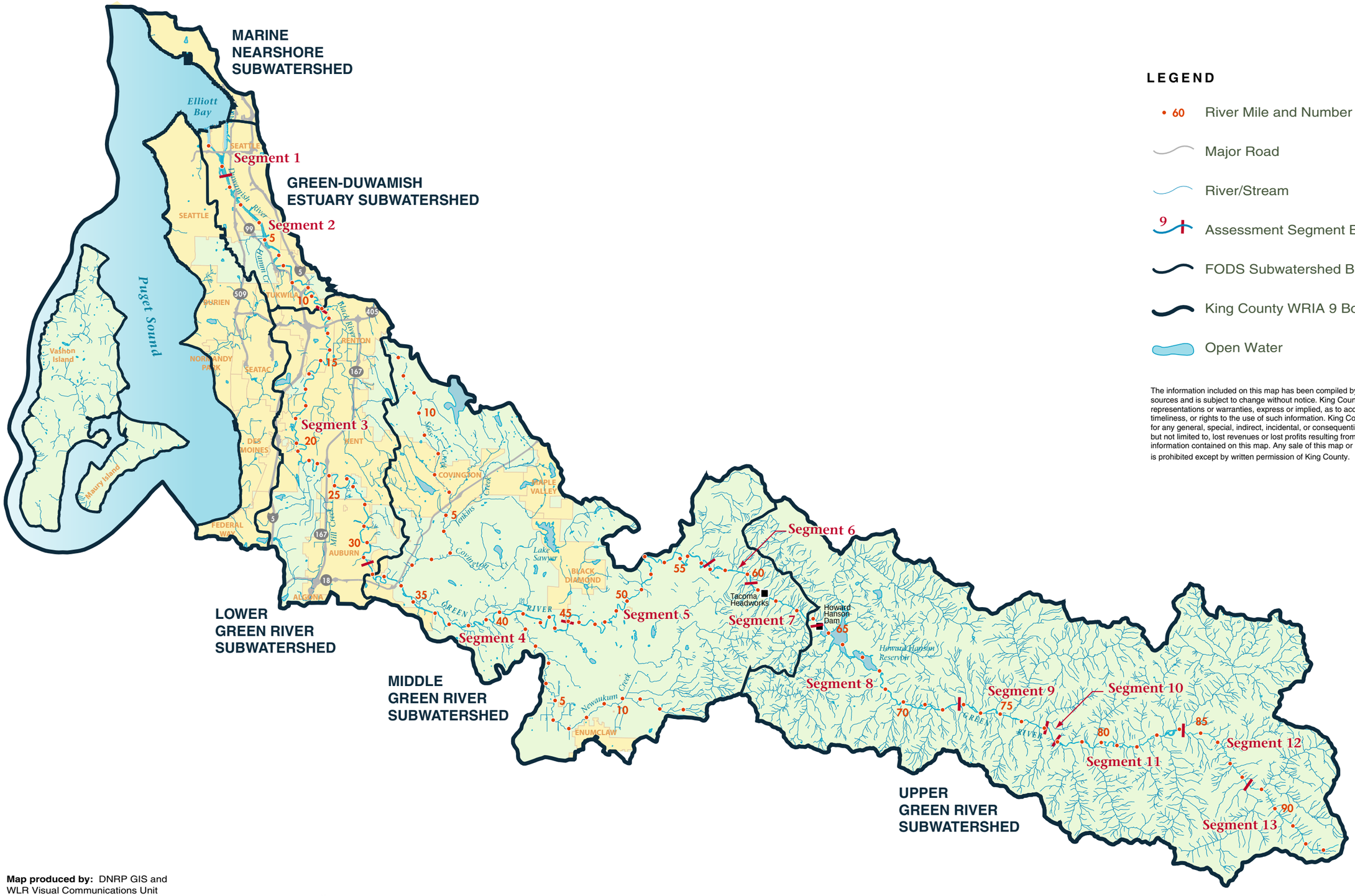
Thirteen assessment segments were identified for analyzing the Green/Duwamish River in terms of aquatic habitat and ecological processes (Figure 4.1, Table 4.1). The criteria for segments described in this report were of valley form, channel geomorphology, slope, and confinement, modified by distinct geologic features such as bedrock controls and impinging bluffs.

For this study, the objectives for these segments were as follows:

- Provide a consistent basis for comparing current in-river habitat structure with historical structure;
- Provide a basis for comparing current riparian structure with historical structure;
- Provide a basis for comparing the geomorphic, hydrologic, and biologic processes operating throughout the river system that control structure;
- Provide a basis for analyzing the effects of management actions on the process, structure and function of the river ecosystem; and
- Provide a basis for linking salmon population dynamics to river dynamics.

Table 4.1. Assessment Segments of the Green/Duwamish River used to analyze aquatic habitat change. ([1] River miles are estimated from Williams et al., 1975)

River Mile[1]	Segment ID	Assessment Description	Subwatershed	Historical Channel Type	Current Channel Type	Slope (%)
0–1.5	1	Tidal Delta	Duwamish	Estuarine	Artificial Constrained	0.09
1.5–11	2	Duwamish Valley	Duwamish	Estuarine	Artificial Constrained	0.003
11–31.3	3	Lower Green Valley	Lower Green	Palustrine (RM 11to 25); Floodplain	Artificial Constrained	0.05
31.3-45.3	4	Middle Green Valley	Middle Green	Unconfined Floodplain	Unconfined Floodplain	0.23
45.3–57.6	5	Green River Gorge	Middle Green	Large Contained	Large Contained	0.85
57.6-60.5	6	Boulder Zone	Middle Green	Unconfined Floodplain	Unconfined Floodplain	0.60
60.5-64.4	7	Eagle Gorge	Middle Green	Large Contained	Large Contained	0.75
64.4-72.7	8	Reservoir Plus	Upper Green	Unconfined Floodplain	Seasonally Inundated	0.55
72.7-77.0	9	Smay Valley	Upper Green	Unconfined Floodplain	Unconfined Floodplain	0.72
77.0-77.9	10	Mile Canyon	Upper Green	Large Contained	Large Contained	0.02
77.9-84.1	11	Lester	Upper Green	Unconfined Floodplain	Unconfined Floodplain	0.83
84.1–88.3	12	Intake Valley	Upper Green	Unconfined Floodplain	Unconfined Floodplain	1.50
88.3-93.6	13	Headwaters	Upper Green	High Gradient Confined	High Gradient Confined	11.30



LEGEND

- River Mile and Number
- Major Road
- River/Stream
- Assessment Segment Boundary & No.
- FODS Subwatershed Boundary
- King County WRIA 9 Boundary
- Open Water

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King County
Department of Natural Resources and Parks
Water and Land Resources Division

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June 2004

Figure 4.1
Green River Assessment Segments

4.3. CHANGES IN FRESHWATER HABITAT

4.3.1. Upper Green River Subwatershed

4.3.1.1. The Valley Bottom

The valley bottom width ranges from approximately 75 meters in Reach 8 (Segment 11) to 900 meters near the town-site of Lester in Reach 9 (Segment 11). Within Reaches 4 and 5 (Segments 8 and 9), side channels, relict channels, and isolated valley bottom wetlands were found to be common (Laird 1997). Approximately six km of groundwater fed side channels parallel the Green River within Reach 8 (Toth et al. 1996).

Historical riparian vegetation commonly includes alder, cedar, hemlock, and maple. The largest size diameter trees ranged from 90 – 182 cm and were dominantly cedar trees (*Thuja plicata*). Yew (*Taxus brevifolia*) and spruce (*Picea sitchensis*) are also infrequently mentioned. The current riparian vegetation along the valley bottom is predominantly small to medium sized deciduous or mixed deciduous and coniferous stands. There are virtually no trees in the valley bottom that are within the 90–182 cm size class such as those noted by Brown in 1891. For more information on historical conditions, see Section 2.3.1.1.

Brown (1891) describes wetlands near the confluence of the Green River and North Fork Green River as a "spruce and cedar swamp 27.50 chains" (approximately 550 meters wide). This location corresponds to two inter-connected swamps identified and mapped by the US Army Corps of Engineers, with a total size of approximately 32 hectares (Sylvester and Carlson 1961). These wetlands were connected to the North Fork Green River by an outlet channel and likely provided rearing area and refugia from high flows for salmonids. The wetlands were inundated by Howard Hanson dam in 1961.

4.3.1.2. Change in the 100-year floodplain

The primary impact on the 100-year floodplain for the Upper Green River was the construction of the roads, railroad grade, and dam. These features have impinged upon the floodplain in all the reaches throughout the study area, notably in Reaches 4 and 5 (RM 70–75.5, within portions of Segments 8 and 9).

4.3.2 The Mainstem Channel

In the Upper Green River, the interaction between sediment supply and transport capacity has influenced the change in channel pattern. The mainstem has substantially increased between 1901 and 1997 in active channel width (Figure 4.2) and channel area in Reaches 3, 4, 5, and 9 (Segments 8, 9, and 11). In contrast, Reach 6, with one of the highest gradients, remained consistent in width and area, and Reach 7 (Segment 10) decreased in channel width between 1901 and 1998; both appear to be effectively transporting sediment. Reaches 1 (RM 64.5–65.3, Segment 8) and 2 (RM 65.3–67.8, Segment 8) are now seasonally inundated by Howard Hanson reservoir.

In Reach 3 (RM 67.8–70, Segment 8), the increase in channel width and area appears to be a function of sediment deposition in channel bars due to the reduction in transport capacity at, and upstream of, the reservoir low-water stage. In Reach 4 (RM 70.0–72.7, Segment 8), the increases that occurred between 1901 and 1964 may be the result of logging along the valley bottom during this period.

Smay Creek has been identified as a major source of sediment from road related failures (Faulknor 1997) and has significantly affected Reach 5 (RM 72.7–75.5, Segment 9). The majority of the channel width increase is in channel bars with over a 400% increase in channel bars between 1964 and 1997.

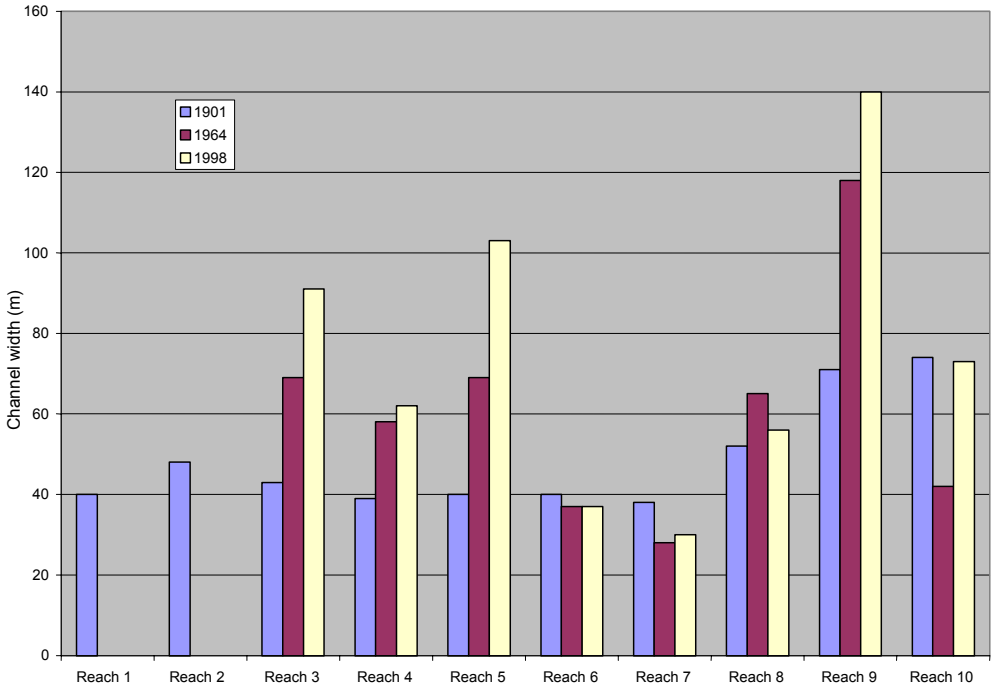


Figure 4.2. Comparison of active channel width over time for the Upper Green River

The valley bottom in Reach 8 (RM 78.0–83.0, Segment 11) was extensively logged in the 1920s (USFS 1996) and the channel recovery between 1964 and 1998 may reflect hydrologic recovery and bank stabilization as the timber stand matured during this period.

Reach 9 (RM 83.0-84.1, Segment 11), located immediately downstream of the confluence with Sunday Creek, has increased in channel width from 71 to 140 meters between 1901 and 1998 and active channel area has increased by 136%. Toth et al. (1996) determined that approximately 75% of this reach was comprised of point, medial, and multiple bars with sediment coming from Sunday and Twin Camp Creek. This corresponds to increases in channel bars between 1964 and 1998.

4.3.2.1. Change in Sinuosity

Channel patterns change in response to discharge or sediment, and this adjustment takes place over a period of years (Richards 1982). Sinuosity, as a measure of channel pattern, generally reflects the degree of habitat complexity. Channel sinuosity was compared between 1964 and 1997. The 1901 and 1910/11 USGS topographical maps were used for comparison. Problems with historical topographical maps included difficulties with the cartographic techniques of that era and that the map scale was relatively low. This resulted in the mapped streams appearing relatively straight, with extremely low sinuosity for a natural system.

The greatest amount of change occurred within Reach 7 (Segment 10), where the Green River changed from a sinuous to straight channel form, with a decrease in sinuosity from 1.24 to 1.03. This corresponds to a relatively high percentage (31%) of the channel influenced by road and railroad revetments in this reach, which may be limiting lateral channel migration.

Sinuosity increased by approximately 10% in Reaches 8 and 9 (Segment 11). These reaches also increased substantially in active channel area and width, and it appears that this increase may be related to lateral channel changes as a result of sediment load exceeding transport capacity. While increased sinuosity generally indicates greater habitat complexity, the amount of channel widening and increase in channel bars within these reaches appear to have decreased habitat complexity for salmonids.

4.3.2.2. Change in Channel Edge

The primary change in channel edge over time has been the construction and maintenance of logging roads and the railroad grade. Revetments constructed of large riprap have been placed along the channel edge to protect the road and railroad grade from erosion. Between RM 61.5 and 88, over 22% of the channel edge has been impacted by these revetments. This amount varies between reaches, with only 5% of Reach 3 (Segment 8) modified by revetment to over 31% of Reach 7 (Segment 10). The net effect of this on the stream channel is a reduced ability of the stream to meander, a disconnect of the river from side channels and the floodplain, elimination of large woody debris recruitment, loss of stream shade, reduction in allochthonous inputs, and increased water velocities.

4.3.3. Tributaries and Side Channels

Tributary stream channels influence the mainstem channel through contribution of flow, sediment, and large woody debris. Most of the tributaries to the upper Green River have been affected by timber harvest and associated road building, railroad construction and maintenance, and construction of Howard Hanson dam. Within the Hanson and Smay Creek sub-basins, many of the tributaries were subject to repeated episodes of landslide and debris torrents that commonly resulted from road failures (Faulknor 1997). These tributaries were also identified as being highly vulnerable to fine sediment deposition (Larid 1997). Within the Lester sub-basin, many of the tributary basins have been affected by fine sediment from mass wasting scarps and road erosion (Toth et al. 1996).

The tributaries that appear to be most substantially affected by anthropogenic changes include the North Fork Green River, Smay Creek, and Sunday Creek. The construction and impoundment of Howard Hanson dam resulted in the loss of 5.6 km of tributary habitat in the North Fork Green River, Gale Creek, and unnamed tributaries.

The lower reaches of Smay Creek increased in width by 300% between 1976 and 1982 as a result of sediment delivery from debris torrents and a deep-seated earthflow (Faulknor 1997). Channel morphology has shifted from a single-thread channel to braided in reaches and to a plane-bed condition, which is not commonly found in unmanaged forest conditions. Mapping of historical channel locations between 1958 and 1995 in Sunday Creek found significant channel widening in the lower gradient reaches (O'Connor 2002). These changes are the result of a high mass wasting rate predominantly from road-related failures in the Sunday Creek basin (Krogstad and Reynolds 2002).

Side channels are fed by the discharge of groundwater from the valley wall or water table. These are often relict mainstem channels remaining after the river is forced out of the channel into the floodplain (Chamberlin et al. 1991). Within Reaches 4 and 5 (Segments 8 and 9), side channels, relict channels, and isolated valley bottom wetlands providing off-channel habitats were found to be common (Laird 1997). However, many historic side channels within Reaches 6, 7, 8, and 9 (Segments 9, 10, and 11) were noted as being isolated from the mainstem channel by the railroad grade (Toth et al. 1996). Groundwater-fed

side channels occur adjacent to the Green River in Reach 8 (Segment 11), approximately 9 km in total length (Toth et al. 1996). However, the large-scale changes in channel morphology within this reach could impact the occurrence and abundance of hyporheic flow.

4.4. MIDDLE GREEN RIVER SUBWATERSHED

4.4.1. The Valley Bottom

The valley bottom change analysis was only performed for Segment 4, from RM 32 to 45.3, because of the availability of historical habitat conditions. In addition, the section of valley bottom is wider and has experienced significant land cover change (Table 4.2), as compared to the narrow valley floor of the other assessment segments. For this analysis, the Middle Green River floodplain refers only to RM 32 to 45.3.

Historically, the valley bottom was heavily forested. Bigleaf maple and western cedar appear to be most common. Douglas fir, and black cottonwood were other tree species found in the floodplain forest. Other woody species included vine maple, red alder, Oregon ash, Pacific dogwood, and bitter cherry (Collins and Sheikh 2004). For more information on historical conditions, see Section 2.3.1.1.

The forest that once covered the valley bottom has become fragmented and the vegetation composition has changed. Today, only about 40% of the valley bottom is forested. On-the-ground survey have not been conducted on the remaining forested areas, but species composition and age structure appears to have shifted. Heavy logging occurred historically within this area and as a result many of the old growth conifers were removed. Today, there are few old growth trees and deciduous tree species appear dominate.

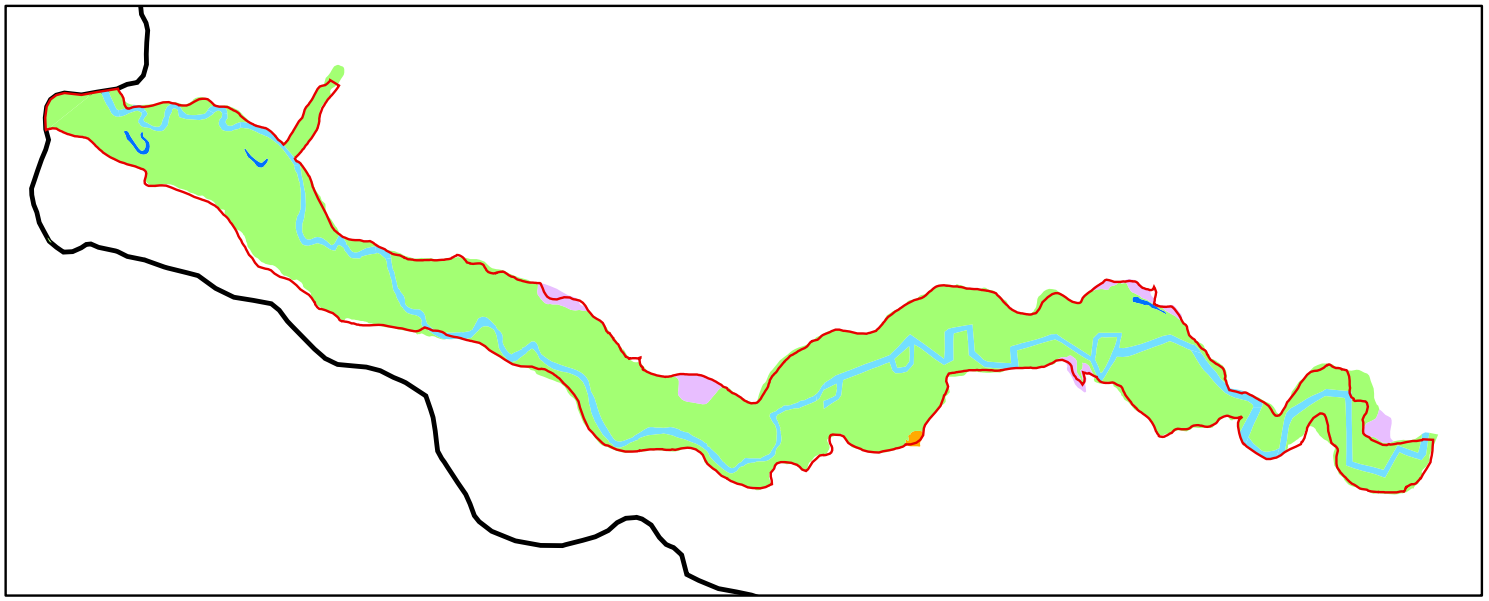
Currently, the agricultural production district comprises 74% of the valley bottom. As a result, more than half of the forested valley bottom (636 ha) has been converted to agricultural uses (Table 4.2 and Figure 4.3). An additional 3% has been cleared for residential development, mostly below Soos Creek near Auburn. The road density is 2.8 km/km^2 within the valley bottom, which is approximately one-third the road density found in the Lower Green River subwatershed. There are eleven road crossings.

Table 4.2. Total Area for Historical and Current Land Cover Area from river mile 32 to 45.

Items in parentheses are included in the total area for forested floodplain.

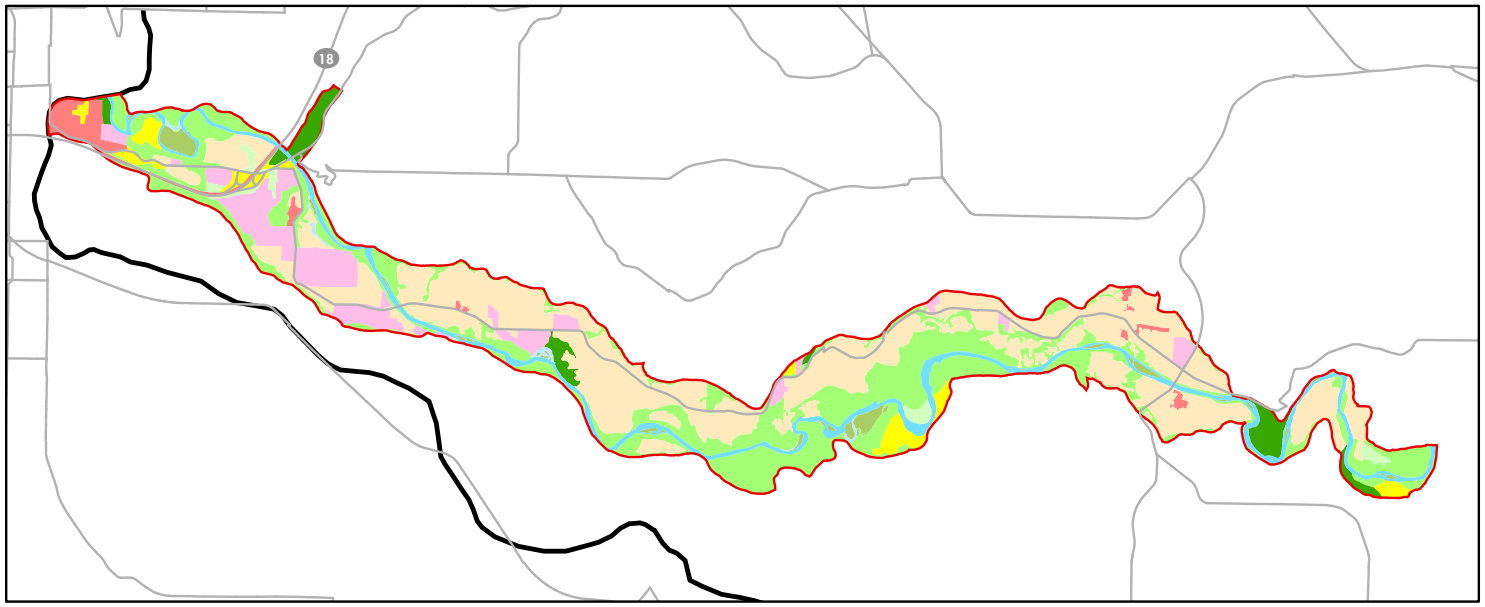
Cover Type	Historical Floodplain (Hectares)	Current Valley Bottom (Hectares)	Current 100-yr Floodplain (Hectares)
Forested Floodplain	1137.7	483.1	315.0
(Forest Fan)	(2.5)	-	
(Forest Shrub)	-	(46.6)	(29.9)
(Forest Islands)		(22.2)	(22.2)
(Shrub)	-	(15.5)	(12.0)
Cropland		111.2	77.5
Pasture		524.8	157.8
Open Areas (wetlands, meadows, lawns)		25.8	9.4
Built	-	38.8	2.7
Ponds	2.5	4.3	4.3
Mainstem Channel	139	91.5	91.5
Total Area	1279.2	1279.5	658.2

No wetlands were recorded in the GLO field notes for the Middle Green River floodplain, however, it seems likely that wetlands were present historically within the floodplain (Collins and Sheikh 2004). The lack of identified wetlands historically may be due to limitation of the transect spacing, typically wetlands were not classified as "classic" wetlands historically (e.g., swamps), and the dynamic nature of the river migration zone could have prevented wetlands from establishing. According to the U.S. Fish and Wildlife Service (USFWS) National Wetland Inventory (NWI) GIS data, there are currently 120 ha of wetlands (USFWS 1990).



Historical Landcover Circa 1865

- Middle Green Floodplain
- Middle Green Sub-Watershed
- Channel
- Pond
- Forested Fan
- Forested Floodplain
- Forested Terrace



Current Landcover Circa 2000

- Middle Green Floodplain
- Middle Green Sub-Watershed
- Built
- Cropland
- Forested Island
- Forest/Shrub
- Forest
- Main Channel
- Open
- Pasture
- Shrub
- Wet Area/Side Channel

King County
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Water and Land Resources Division

Map produced by:
DNRP GIS and WLR Visual Communications Unit

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0 1 2
Kilometers

Figure 4.3
Middle Green River Subwatershed Landcover Comparison

4.4.1.1. Change in 100-Year Floodplain

Even today, the middle Green River valley appears to play a large role in attenuating flood peaks (Perkins 1993), but under historical conditions the Middle Green would have played an even greater role. Historically, the river migrated throughout the valley bottom, therefore the entire valley bottom functioned as the floodplain and performed a number of vital functions that affect the quality of salmonid habitats. Today, the river can no longer migrate freely throughout the valley bottom due to the 27 levees and revetments totaling 8.7 km (approx. 5.4 miles) in length, as well as regulated flows out of Howard Hanson. The new 100-year floodplain is approximately half the size (52%) of the historical floodplain and is now a mosaic of forests and cleared agricultural lands. Accessible floodplain forests have been reduced by 72% (Table 4.2). Despite these flood control efforts, parts of the valley bottom flood every year (Perkins 1993).

4.4.2. Mainstem Channel

The mainstem channel of the Middle Green River subwatershed is variable, alternating between wide valley bottoms and narrow canyons. In 2001, R2 Resource Consultants (2002) surveyed the mainstem of the middle Green River for habitat conditions and this was used as the current conditions whenever possible, see *Green River Baseline Habitat Monitoring* report. The six reaches used in this survey are relatively close to the change analysis assessment segments, allowing their summary statistics to be used.

Our findings show that all assessment segments had a reduction in total channel area (Table 4.3). Channel area for Segments 4 and 7 is ~34% less than historical conditions; Segment 6 is ~29% less. This reduction in channel area is likely a result of bank armoring and reduction of flood flows. Segment 5 was not examined because the channel area and channel width have stayed relatively constant due to confinement of the Green River Gorge.

Table 4.3. Comparison of Mainstem Channel Area for Middle Green Assessment Segments

Assessment Segment	Historical Channel Area (ha)	Current Channel Area (ha)	Percent Change
Segment 4	145	96	-34
Segment 6	17	12	-29
Segment 7	22	15	-34

A decrease in channel width is an expected outcome from the flood control efforts of the Howard Hanson Dam and training levees. Segment 4 had the highest channel width decrease (36%) (Table 4.4). Roads impacted 51% of Segment 7 in 1998 as compared to 46% impacted by the railroad in 1901. In contrast, Segment 6 only had 7% of the channel impacted in 1998 while 61% was impacted by the railroad in 1901 (the railroad was relocated away from the channel in 1959 when the dam was built). The associated levees that protect roads, railroad, and property, constrict the channel and prevent the river from meandering. The levees also result in changes in flow dynamics that often increase velocity, reducing the ability of the river to dissipate energy and sediments.

Table 4.4. Bankfull width change for segments within the Middle Green subwatershed.

([1] represents mid-1860s conditions; [2] represents 1901 conditions; [3] represents 2001 conditions).

Assessment Segment	Historical Bankfull Width (meters)	Current Bankfull Width	Percent Change
Segment 4	66.1[1]	42.5[3]	-36
Segment 6	39.0[2]	41.0	5
Segment 7	36.0[2]	33.0	-8

4.4.2.1. Change in Sinuosity

Although channel area and channel width has decreased in almost all segments, sinuosity has stayed relatively the same over time (Table 4.5). The existing flood control structures (levees/revetments) captured the channel pattern in the 1960s at the time of construction and prevent lateral channel migration such as cutoffs and meander shifts from occurring.

Table 4.5. Sinuosity for segments within the Middle Green subwatershed

([1] represents mid-1860s condition, [2] represents 1901 conditions, [3] represents 2002 condition, [4] represents 1998 conditions, [5] Based upon classification by Mount, 1995. NA = represent not applicable based on the assumption that sinuosity would be constant due to valley confinement).

Assessment Segment	Historical Sinuosity	Current Sinuosity	Channel Pattern[5]	Percent Change
Segment 4	1.24[1]	1.28[3]	Sinuous	3
Segment 5	NA	NA	NA	NA
Segment 6	1.04[2]	1.02[4]	Straight	-2
Segment 7	1.00[2]	1.03[4]	Straight	3

Historically, the river migrated throughout the valley bottom. Within Segment 4, levees impact 39% of the total channel length but the longest stretch of unconstrained channel is between RM 38 to 41, often referred to as the Metzler-O'Grady reach (Figure 4.4). This dynamic reach provides important habitat by currently supporting naturally spawning Chinook, steelhead, chum, some coho and a few sockeye and pink salmon. This reach is a braided channel with multiple flow paths and large transverse and mid-channel bars (R2 2002). Although this channel pattern was more common historically, today it is the only reach of its kind in the middle Green River. The rapid channel migration observed there over the years is indicative of depositional conditions for both sediments and large woody debris (Perkins, 1993).

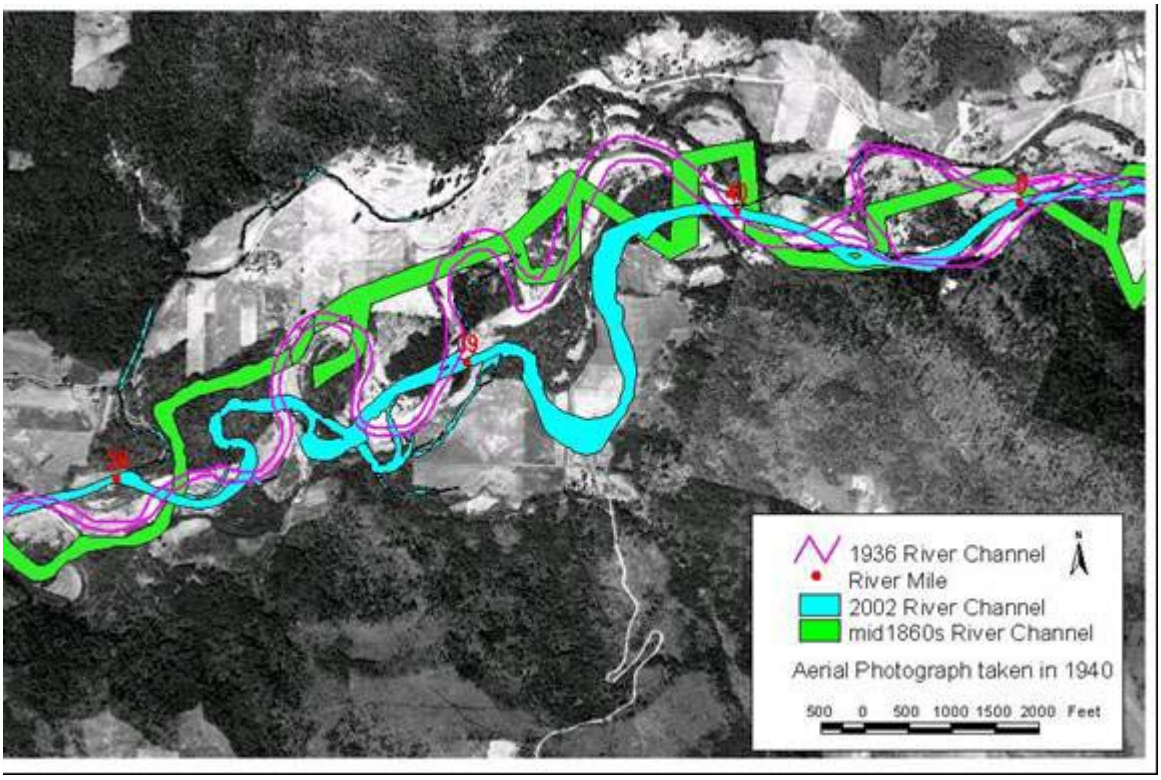


Figure 4.4. Lateral Channel Migration in Metzler-O'Grady reach.

4.4.2.2. Change in Channel Edge

An examination of mainstem channel edge shows that it has actually increased over time (Table 4.6). The primary explanation for increased channel edge is the increase in forested islands within the mainstem channel. These islands have established mature trees and shrubs due to the reduction of flooding events that would otherwise eliminate this vegetation. The ability to map these forested islands from high-resolution 1-meter orthophotographs that allow for more precise delineation of these forested islands have resulted in bias of current conditions. Forest islands account for 14% (7.2 km) of total channel edge length for Segment 4 and 2.5% for Segment 7.

It should not be assumed that channel edge is equivalent to channel edge habitat,because the latter would factor in depth as a component. Nor should it be assumed that all channel edge represents suitable habitat because alteration of bank conditions via levees has resulted in steeper bank slopes. Channel edge is another attribute to describe the river channel and how it may have changed over time. Further examination is needed to further define suitable channel edge habitat.

Table 4.6. Channel edge length for segments within the Middle Green River subwatershed

[1]represents mid-1860s condition, [2] represents 1901 conditions, [3] includes forested island.

Segment	Historical Channel Edge (km)	2002 Channel Edge (km)[3]	Percent Change
Segment 4	50[1]	53.2	6
Segment 5	NA	45.5	NA
Segment 6	8.9[2]	9.1	0.2
Segment 7	12.3[2]	13.9	12

4.4.3. Tributaries and Side Channels

The Middle Green River Subwatershed has two larger tributaries and several smaller tributaries that provide spawning habitat and rearing habitat for salmonids. The Soos Creek and Newaukum Creek subbasins currently provide significant spawning habitat and some rearing habitat for chinook salmon. Other documented tributaries used by salmonids are Unnamed Creek 0098/0099 (Williams et al. 1975), Burns Creek, Crisp Creek, and O'Grady Creek.

The change in tributaries only includes those portions contained within the valley bottom and is limited to channel edge only. In total, tributary channel edge decreased by 19%; Tributary 0098/0099 channel edge decrease of ~45%. All of this channel edge loss occurred in headwaters that are completely contained within the floodplain. Historically, the headwaters of Creek 0098 appears to have connected to the mainstem, and was likely maintained through frequent flooding. According to the Middle Green River Topographic Survey, this remnant side channel still exists but is no longer feeding the tributary. Historically, it is likely that juvenile Chinook were flushed into this side channel during high flow events and reared in this creek.

The mouth of Burns Creek appears to have been relocated and has experienced an influx of reed canarygrass (*Phalaris arundinacea*); the presence of many salmonids has been documented. The last creek to be analyzed is Crisp Creek (also known as Keta Creek). A dam at the Keta Creek Hatchery facility pond at RM 1.05 prevents further upstream migration by salmonids. Historically, cascades located approximately a 0.5 mile upstream (WDFW SSHAIP 2004) were likely a fish barrier. The channel edge of Crisp Creek has decreased by ~16%, with the most significant change in channel edge occurring at the mouth. Historically, the creek likely flowed into a large side channel, approximately 1.5 km in length.

Historically in the middle Green River, side channels were the dominant type of channel edge creating an extensive network that exited and entered the mainstem river. Most of the side channels were north of the river and were likely created by overbank flows branching through the alluvial deposits of the valley bottom. Historically, there was approximately 54 km of side channel compared with today's estimate of about 13.4 km. This represents a decrease of 75%, which is slightly greater than to 70% provided by Kerwin and Nelson (2000). Both estimates clearly show a significant loss of side channel habitat that are the result of flood control efforts and land use changes.

4.5. LOWER GREEN RIVER SUBWATERSHED

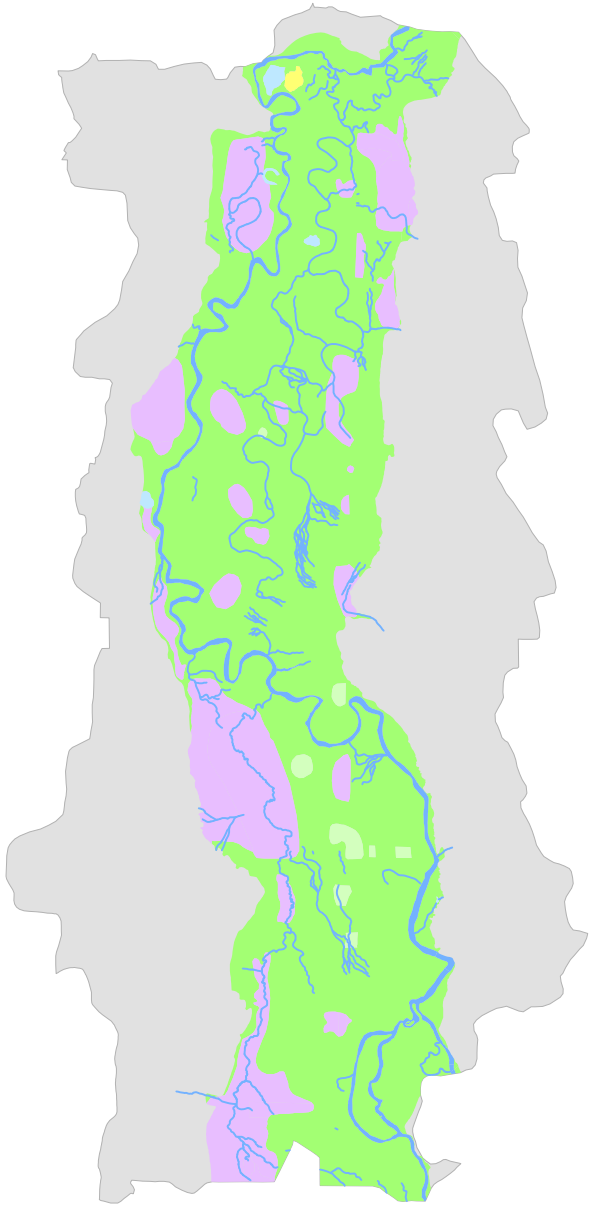
4.5.1. The Valley Bottom

The subwatershed and its hydrology have dramatically changed over the last 150 years. Historically, the White River, the Black/Cedar River, and the Green River all joined in this reach to form a single large river. Today, only the Green River contributes any major flow to this section of river.

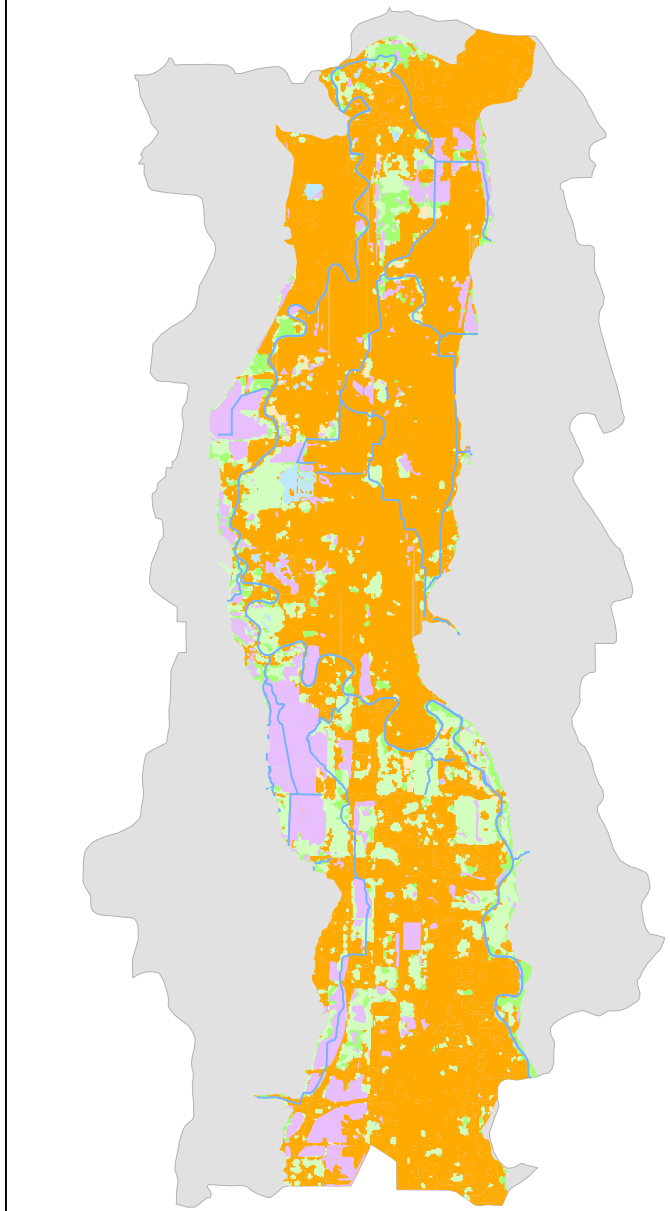
Historically, the floodplain was a mosaic of floodplain forest and wetlands (Figure 4.4). Black cottonwood was the most abundant large diameter tree and 42% of the basal area (Collins and Sheikh 2004). Other less abundant large diameter bearing trees in the Lower Green River valley bottom were western cedar, Douglas fir, and bigleaf maple. For more information on historical conditions, see Section 2.3.1.3.

The Lower Green valley bottom has been dramatically altered from the once densely forested floodplain with numerous large "swampy" wetlands scattered throughout (Table 4.7). The most obvious and significant land cover change has been urban development. It is estimated that ~60% of the valley bottom is either high density (100% impervious) or low density (50% impervious) development. Road density is 8.1 km/km^2. There are 69 road crossing in the Lower Green River subwatershed.

The result of this development has been the clearing of the floodplain forest (~87%) and the filling of wetlands (~40%). Historically, there were several large wetlands located in the major tributary drainages and numerous smaller wetlands were scattered throughout the valley bottom. The total area of historical wetlands was estimated at 1,495 ha (3,694 acres) as compared to 927 ha (2,294 acres) today (Collins and Sheikh 2004; USGS 1990). In the present Southcenter Mall area, there was a large wetland historically. This 159 ha (392 acres) wetland was completely filled except for a small area The low elevation in this area allowed for frequent flooding of the wetland, causing inundation to ~1m. Historically, there was also another 109 ha (269 acres) wetland further south on the west side of the river that was described as a "cranberry marsh." This wetland was unique because it was symbolized on the GLO plat map with numerous springs. Today, this area remains relatively undeveloped but it is cleared and appears to be used for agriculture; it appears to be drained by Johnson Creek.



Historical Landcover Circa 1865



Current Landcover Circa 2001

LEGEND

- Forest
- Herbaceous/Historical Prairies
- Uplands
- Built
- Bare Earth
- Wetlands
- Channel
- Water
- Lower Green River Subwatershed

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Miles

Map produced by:
DNRP GIS and WLR Visual Communications Unit

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Figure 4.5

Lower Green River Subwatershed Landcover Comparison

Table 4.7. Total Area for Historical and Current Land Cover Area from river mile 11 to 32.

Items in parentheses are included in the total are for forested floodplain.
([1] Source is mid-1860s General Land Office survey notes; [2] Source is 2001 Landsat Landcover GIS data; [3] Source is 1990 USGS National Wetland Inventory (estimate high); [4] Total area includes the Black and White Rivers; [5] Total area includes the Black River).

Cover Type	Historical Floodplain[1] (Hectares)	Current Valley Bottom[2] (Hectares)	Current 100-yr Floodplain (Hectares)
Forested Floodplain	6,028.8	797.3	265.4
(Forest Fan)	(4.6)	-	-
(Forest Shrub)	-	-	-
(Forest Islands)	-	-	-
(Shrub)	-	(432.8)	(124.0)
Upland Bedrock	15.8	-	
Bare Earth	-	55.3	8.3
Herbaceous vegetation (historical prairies, grassy areas)	76.2	1,285.0	403.3
Wetlands	1,494.8	927.4[3]	583.3[3]
Built (high or low density development)	0.0	4,722.0	623.7
Water (Ponds, lakes)	29.3	60.9[5]	28.0[5]
Mainstem River Channel	304[4]	101.0	101
Total Area	7,949	7,949	2,004

4.5.1.1. Change in the 100-year Floodplain

Historically, the mainstem channel flowed unconfined through the valley bottom and frequent flooding occurred. These events upset the early settlers in this area who were clearing the valley bottom to use the land for cultivation. Today almost the entire channel is constrained by levees or revetments on either or both banks that have allowed heavy development to occur. There are 86 levees and revetments totaling 43 km (approx. 26.7 mi) in length (five times the length along the Middle Green River). Only small stretches remain without a levee or revetment on both stream banks. These levees and revetments result in unnaturally steep armored streambanks with elevated riparian vegetation. The effects are increased velocities during high flow periods, decreased refuge, decreased nutrient/prey input, and poor quality riparian vegetation.

If the river historically flooded the entire valley, then a significant change to the floodplain has resulted from flood control activities. The new 100-year regulatory floodplain is approximately 25% in size of the historical floodplain. In other words, 75% of the valley bottom is no longer impacted by floods nor

provides or contributes any ecological benefit during flood events. The dominant land cover within the current 100-yr floodplain is urban development (30%), followed by wetlands (29%) and herbaceous vegetation (20%). Forested floodplain represents only 13%, of which 48% are shrubby species with a large portion likely being noxious Himalayan blackberry (*Rubus discolor*) along the levees.

4.5.2. Mainstem Channel

The current mainstem channel of the Lower Green River subwatershed has been completely channelized and the natural geometry of the channel has been changed. Under natural conditions, the mainstem channel is capable of providing a variety of habitat types that support ecological diversity (Richards, 1982). Channelization and levees result in loss of the quality and quantity of habitat diversity (Mount 1995).

Channel area and channel width were reduced by more than 50% (Table 4.8). The primary causes of this reduction are the diverting of the White River and flow control on the Green River. These activities significantly reduced the water flow in the Lower Green, resulting in smaller, narrower, channel. The extensive system of levees and revetments furthered confined the mainstem channel. These changes in channel morphology negatively impact the quality and quantity of rearing and spawning habitat.

Table 4.8. Change in Channel Morphology for Segment 3

([1] Source is GIS data created using mid-1860s General Land Office survey notes (Collins and Sheikh 2004) ;[2] Source is GIS data using orthophotos; [3] Source is GIS data created by in the field measurements (Anchor 2004).

Attribute of Change	Historical Conditions (mid-1860s)[1]	Current Conditions (2003)	Percent Change
Channel Area	224 hectares	98 hectares[2]	-56
Channel Bankfull Width	72 meters	34 meters[3]	-53
Sinuosity	1.63	1.72[2]	5
Channel Edge	63 km	66 km[2]	5

Sinuosity and channel edge show a slight increase (5%) over time (Table 4.8). Based on sinuosity, the morphology can be described as a single meandering channel; however, the erosional and depositional behavior of point bar formation and lateral accretion that is characteristic of this channel type is not currently present. Historically, the Lower Green River mainstem channel carried large amounts of fine sediments that would be deposited along the riverbanks during overbank flows (Chittenden, 1907; Ober 1898; Collins and Sheikh 2004). The levees that were constructed during the last century were built on top of these natural levees capturing the historical sinuosity, explaining the minimal changes in sinuosity. It is likely that the channel area between the historical low water flow and the natural levees were filled in, reducing total channel area. It is likely that the channelization and bank armoring results in juvenile salmonids being flushed through the Lower Green river during high flow periods, and it has been hypothesized that this is due to lack of suitable refuge habitat (Nelson et al. 2004).

4.5.3. Tributaries and Side Channels

Historically, tributaries were the dominant type of channel edge in the lower Green River because of the geologic and glacial processes that formed this section of river. As mentioned, flooding was common, creating a network of flood channels that fed the tributaries and wetlands. Tributaries provided important habitat and accounted for approximately one-third of total channel area and 62 percent of channel edge (Collins and Sheikh 2004). Side channels contributed about 6.5 km of channel edge habitat. During the frequent flood events, it ispossible that the floodwaters carried with them juvenile salmonids who ended up in the tributary and wetlands complexes.

Today, the tributaries are heavily altered due to development of the floodplain and are rarely fed by floodwater. Approximately 20% of Springbrook Creek is contained in drainage ditches and its confluence is upstream of the Black River Pump Station, a significant fish passage barrier. Water quality (temperature and dissolved oxygen) is also a problem for this creek (see Section 3.2). Mill Creek and Mullen Slough are also important tributaries that have been altered. The wetlands that fed them have become degraded due to roads and fish passage barriers are also a problem.

4.6. CHANGE IN IN-CHANNEL WOOD

Riparian stand characteristics and in-channel wood recruitment, also referred to as large woody debris (LWD), is influenced by many factors including: stream morphology and processes; fire history regime; tree mortality through insects and disease; debris torrents; mass wasting and bank undercutting; and timber harvest (Spence et al.1996). Depending on the stream size, the role of LWD will vary. In higher order streams, like the Green River, the role of LWD is less documented. It appears that historically, LWD played a major role in floodplain and channel development (Sedell and Luchessa 1981). It increases channel complexity by creating side channels, backwaters, ponds, and refuge for aquatic organisms during high flow events.

Information on historical in-channel wood for the Green River is limited. It was described that trees along the banks are constantly being undermined and dropped into the channel (Chittenden). Snagging was conducted irregularly and was mostly confined to the Duwamish River and Lower Green River, upstream of Kent to the upstream limit of navigation. It is presumed that the reason for limited snag removal was primarily due to relatively little commerce using the Green River, that was instead using the railroad instead (Collins and Sheikh 2004). By 1884 the Northern Pacific Railway between Seattle and Tacoma was built that all but eliminating the need for steamer activity on the lower part of the river. Over a 100 years of river clean up has left little fallen trees and LWD jams in the Green River. It is recommended that further study be conducted of the processes that have historically affected riparian vegetation and large woody debris recruitment within the Green River in order to assist with refining a target quantity of LWD.

In order to estimate the quantity of LWD in the Green River prior to European settlement, instream wood studies in unmanaged forest streams in Alaska and Western Washington were used for comparison. For streams similar in size to the Green River, these studies found range of a 240 to 2,080 pieces of large woody debris per km (Table 4.9). Most LWD in pristine systems is usually accumulated in a few jams that can produce high LWD counts. These studies were consistent in using a minimum size criteria for LWD of 10 cm diameter and 1 meter long, except for Robison and Beschta (1990), in which the minimum LWD size criteria was 20 cm diameter and 2 meters long.

Table 4.9. Quantity of LWD pieces per meter for channels >20m in studies of unmanaged forests in Alaska and Washington.

Author(s)	LWD frequency (pieces/km)	Location
Cedarholm et al. (1989)	240	Washington
Murphy and Koski (1989)	458	Southeast Alaska
Robison and Beschta (1990)	420	Southeast Alaska
Fox (2001)	570-2080	Western Washington

Tree species contributing to LWD historically in the Upper Green would have been western red cedar, hemlock, maple, yew, and spruce. A large, stand-replacing fire happened approximately every 200 years with the last large-scale fine occurring in the early 1700s (USFS 1996). Clearing associated construction of the railroad in the 1880s and timber harvest removed much of the wood along the south side of the valley bottom (Toth 1997). More recently, snagging of in-channel wood during timber harvest or stream cleaning was a common practice in the early 1970s and early 1980s. The combination of these practices led to very low quantities of wood in many stream reaches. Recent surveys within Reaches 4 and 5 (Segments 8 and 9), found about 4.5 pieces of large wood (>30.5 cm diameter and 9.1 meters long) per km with much of the woody debris (89%) not functioning within the bankfull channel (USACOE 2002). Within Reaches 7 and 8 (Segments 10 and 11), 21 and 68 pieces LWD/km, respectively, were counted (Toth et al. 1996). It is apparent that the current instream wood count of 4.5 to 68 pieces per kilometer is far less than historical levels base upon wood counts in unmanaged areas.

Tree species contributing to LWD historically in the Middle Green would have been western red cedar, black cottonwood, Douglas fir, Sitka spruce, and bigleaf maple. Historical snagging operations did not include the Middle Green; however, through the use of 1936 aerial photos, one log jam approximately 160 feet long containing 15 to 20 pieces was identified in the Metzler-O'Grady reach (Fuerstenberg et al. 1996). It is likely that several of these large jams existed throughout the river but a complete photo examination was not possible at this time.

Current surveys of the Middle Green found all Segments well below the 50 pieces/km that is considered to create "properly functioning" conditions (NMFS 1999) and the historical estimated range of 240 to 2,080 pieces/km. Segment 4 had between 11 pieces/km for (R2, 2002) to 17 pieces/km (Kerwin and Nelson 2000). Segment 5 had 9 pieces/km; Segment 6 had 6 pieces/km; and Segment 7 only had 3 pieces/km. The unconstrained Metzler-O'Grady reach had the highest density of in-channel wood in 2001 at 16 pieces/mile. Six LWD jams were surveyed including one jam with over a hundred pieces of wood (R2, 2002).

Historically, in the lower Green and Duwamish River, LWD occasionally interrupted river flow and created pool habitat. Snagging operations existed from 1893 to 1906, but it is difficult to ascertain which in-channel logs were the result of land clearing. The 1898 description of snags does inform us about the habitat-forming processes of these jams, such as the accretion of sediments and the formation of bars. Although the creation of pools is not described, it is reasonable to assume that they were also present and provided habitat to juvenile and adult salmon. Many of the log jams described were very large and were sometimes colonized with vegetation, indicating that they were present for long periods of time. During current surveys, two log jams were observed between RM 26.6 to 19.1) (Anchor 2003). From RM 32 to 26.6, a known spawning patch, there were only 12 pieces/km; however, between RM 26.6 to 19 there were 41 pieces/km and between RM 19.1 to 15.6 there were 44 piece/km. LWD decreased by 50%

downstream to RM 11. No distinction was made between naturally recruited LWD and those that were placed within a restoration project.

4.7. CHANGE IN RIFFLE-POOL SEQUENCE

In simplistic terms, instream habitat can be classified as pools and riffles. Riffles are topographic high areas within the channel bed profile and conversely, pools are the low points (Mount 1995). Pools are deep-water areas that are preferred habitat for both adult and juvenile salmonids. The relationship between channel width and riffle-pool geometry can be used to determine a historical estimate of pools for segments. The pool-to-pool distance generally falls within the range of 5 to 7 channel widths, with the mean being 5.9 (Keller and Melhorn 1978).

In the upper Green River, habitat inventories were conducted in the lower portions of the mainstem identifying a total of 45 pools over a 9-kilometer segment within Reaches 4 and 5 (Segments 8 and 9) (HDR Engineering 2002). This corresponds approximately to a pool spacing of 16 channel widths and appears to correspond to a lack of wood and channel widening within these reaches. Another habitat inventory within Reaches 7 and 8 (Segments 10 and 11) determined a pool spacing of 6 and 3 channel widths, respectively (Toth et al. 1996). This indicates excellent pool habitat within these reaches when compared to the expected historical comparison of 5 to 7 channel width.

In the middle Green River habitat inventory (R2 Consultants 2002) that found that all segments had a pool-to-pool distance greater than 5.9 channel widths (Table 4.10). These findings suggest that the total pool count (and LWD) has changed more rapidly than expected due to the decrease in river size. In conclusion, the pools are fewer and further spaced apart. This decrease in pool frequency suggests that channel complexity has decreased, and riffle-pool geometry may not be functioning, suggesting a change in planform pattern has occurred.

Table 4.10. Pool Characteristics for Middle Green River Subwatershed. Data from R2 Resource Consultants (2002).

Assessment Segment	Pool Frequency (CW/Pool)	Average Residual Pool depth (meters)	Pools formed by LWD (percent)
Segment 4	19	2.0	10
Segment 5	9	2.8	0
Segment 6	11	3.0	0
Segment 7	13	2.7	0

In the Lower Green River the average pool frequency is every 23 channel widths. The average pool frequency for large pools (>50% of wetted width) is 84 channel widths and dominant large pool formation was riprap. It should be noted that from RM 11.0 to 15.6 only one large pool was observed, which affects the total outcome. Between RM 11 and 19 there are only six large pools and 8 small pools. These changes in pool frequency and smaller size suggest that the lower Green River may not be providing adequate adult holding pools for upstream migration. The pools in the lower part of the Segment 3 provide inadequate rearing habitat, resulting in increased competition and early outmigration.

4.8. CHANGE IN ESTUARINE HABITAT

4.8.1. Duwamish Estuary Subwatershed

4.8.1.1. The Valley Bottom

The valley bottom of the Duwamish differs in the lower valley versus the upper valley. Historically, the upper valley resembled the lower Green River with natural levees depositing along the riverbanks, whereas the lower valley riverbanks are lower in elevation than the rest of the valley bottom. Today, armoring and levees have mostly altered the natural riverbanks. King County maintains 6.6 km of levees to control flooding along the Duwamish River, eginning at RM 6 (evees maintained by other agencies are readily available at this time). Historically, this area was prone to flooding as deep as 15ft of standing water. These floodwaters supported ~200 ha of freshwater wetlands that have been decreased to ~7 ha (Table 4.11, Figure 4.6). All but two of these wetlands are far removed from the mainstem river and only a small portion between RM 9.5 and 11 would flood during a 100-yr event. In addition, historically there were riverine-tidal forested and scrub-shrub wetlands but these are completely gone (Blomberg et al. 1988; USFWS 1991).

The diversions of the White and Cedar Rivers, combined with the dewatering of the Black River, has significantly reduced the amount of flow funneling through the Duwamish River and has allowed for the floodplain to be developed into one of the most prosperous regions of Washington State. The result has been that about 75 % of the valley bottom has been converted from aquatic habitat to urban high-density land use (Figure 4.11).

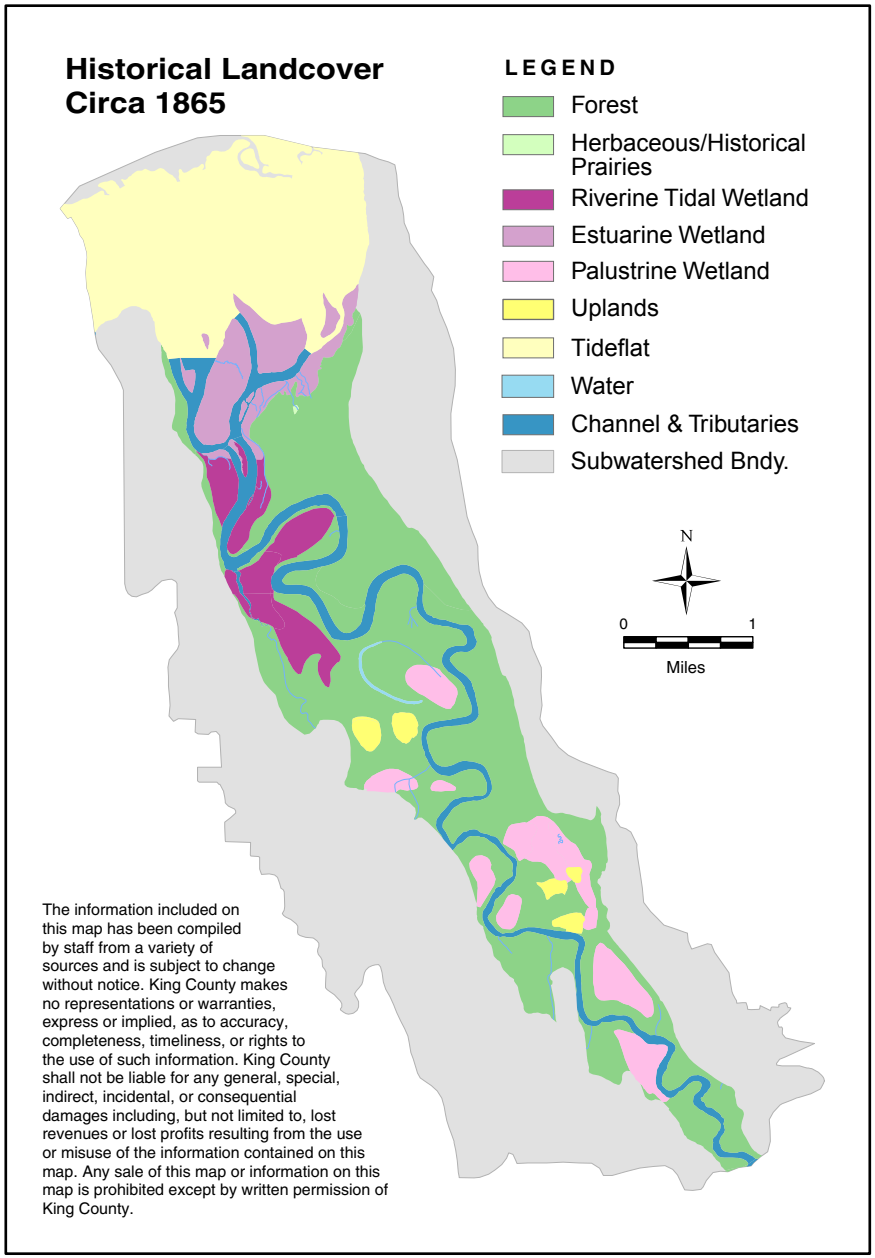
Table 4.11. Total Area for Historical and Current Land Cover Area from river mile 0.0 to 11.

Items in parentheses are included in the total are for forested floodplain.
([1] Source is mid-1860s General Land Office survey notes; [2] Source is 2001 Landsat Landcover GIS data; [3] Source is 1990 USGS National Wetland Inventory (estimate high)

Cover Type	Historical Floodplain[1] (Hectares)	Current Valley Bottom[2] (Hectares)
Forested Floodplain	1,370.0	21.0
(Forest Terrace)	358.0	
(Shrub)		11.0
Upland Bedrock	29.0	
Bare Earth & Mudflats		16.0
Herbaceous vegetation (historical prairies, grassy areas)	0.6	63.9
Wetlands (Palustrine, Estuarine, Riverine-Tidal, Mudflats)	1316.0	20.8
Built (high or low density development)	0.0	2,556.0
Water (Ponds, lakes)	5.0	0.2
Mainstem River Channel	278.2	310.0
Total Area	2,999.0	2,999.0

The historical floodplain forests were diverse with hardwoods being frequent, although few hardwoods were large. Western red cedar, Douglas fir, and Sitka spruce likely contributed LWD. The terraces present were dominated by Douglas fir and were not subject to floods. Floodplain forest have decreased by ~98%. The riparian zone is highly disturbed; between RM 0 to 6 Himalayan Blackberry covers ~30% of the channel edge and ~48% has no vegetation (Terralogic GIS and Landau Associates 2004). Between RM 6 to 11, invasive vegetation accounts for ~84%. These findings clearly show that the functions of riparian vegetation are not present.

Estuarine habitats were extensive historically but are currently found only in small patches. Historical estimates of estuarine mudflats were ~901ha and estuarine wetlands were ~174 ha. Today there is only about 1% left of mudflats and ~11% of tidal marshes (current area represent 1986 conditions (Blomberg et al. 1988)). The filling of the mudflats and the straightening and widening of the former channel has completely altered the estuarine habitat. These transition habitats are important to juvenile salmon for osmoregulation (adapting to saltwater), growth, and survival.



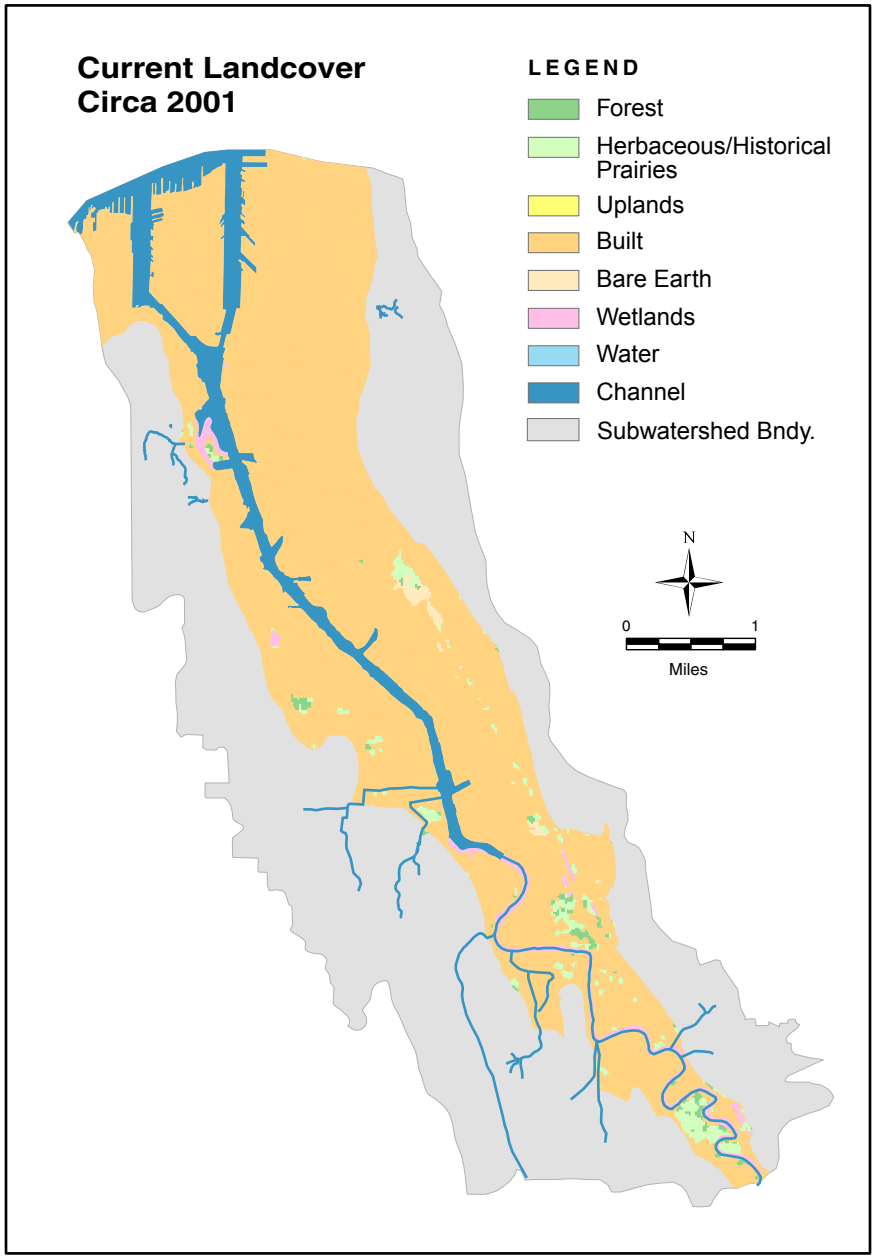


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Figure 4.6
Duwamish Estuary Subwatershed Landcover Comparison

4.8.1.2. The Mainstem Channel

The modification of the Duwamish River began in the early1900s. It included the creation of Harbor Island, dredging to create the East and West Waterways, and channelization of the river up to RM 5.3. The effects of this change have been a replacement of 9.3 miles of meandering channel with 5.3 miles of a straightened channel (Kerwin and Nelson 2000). The straightening and widening of the mainstem river has increased channel area by ~10%; however, it has resulted in the construction of dikes or levees along the entire reach and about 90% of the banks are armored. Despite the increase in channel edge due to the East and West Waterways, the armoring has negatively affected channel edge habitat. Today, there is approximately 60 km of mainstem channel edge, roughly 40% is within the Waterways.

The historical extent of estuarine transitional zone is not completely known, but our assumption is that it occurred around RM 1.5. If this were true, approximately 20% of the mainstem channel would have provided transition zone habitat. The current extent is also not fully known but additional research is proposed by WRIA 9 to determine its geographic extent. High-density juvenile fish use has been seen between RM 5 to 6.5, which researchers believe is used as an osmoregulation transition zone.

4.2.1.3. The Tributaries, Distributaries, and Blind Channels

The current GIS information on distributaries and blind channels is limited, and requires a more thorough data development than is possible at this time. It is reasonable to assume that the current amount is negligible compared to historical levels; however, restoration has been ongoing in the Duwamish Estuary that has created some off-channel habitat. Historically, the distributaries and blind channels provided the much needed slow moving off-channel habitat for juvenile rearing, totaling approximately 30% of channel habitat, whereas tributaries was less than 1%. Blind channels were the most dominant channel edge historically.

4.9. ELLIOTT BAY

Historically, Elliott Bay provided vital habitat for both juvenile and adult salmonids. It was recorded that in the 1860's this area was abundant with salmon (Bagley 1929). It provided approximately 350 ha of tideflats and three small tidal marshes (see Section 2.3.1.5). These marshes have been filled and highly altered, as well as most of the tideflats. Some of the northern portion of Elliott Bay retains some unarmored shoreline, mostly along bluffs of the Magnolia neighborhood. In addition, the western side of Elliott Bay (West Seattle) has lost much of the middle to high intertidal habitat due to bank armoring and urban development; however, some tidal flats still exist at lower elevations.

SECTION 5 – UPDATES TO SALMON ECOLOGY AND HABITAT USE IN WRIA 9

5.I. INTRODUCTION

This section summarizes the findings of numerous independent salmonid studies carried out over the past four years and synthesizes and connects important information to provide support to the Habitat Plan. It builds upon the information presented previously in the Habitat Limiting Factors and Assessment Report (Kerwin and Nelson 2000).

Studies carried out during or after the year 2000 differ significantly from past studies because in the spring of 2000 a program to mass mark juvenile Chinook released from the Soos Creek hatchery was initiated. Mass marking made it possible for the first time to distinguish hatchery Chinook from those born in the natural environment, ushering in a new era for studies of interactions between hatchery and naturally spawned fish. Intensive seining and trapping were the primary sampling tools used to collect large numbers of fish over many months in order to acquire baseline ecological data regarding naturally produced juvenile Chinook. Most of these recent studies focus on Chinook migration timing and relative abundance and growth, which can be used to indirectly assess WRIA-wide habitat use. In addition, similar baseline data were concurrently collected for other non-target salmonid species, including coho and chum salmon.

Numerous studies by the following authors were reviewed and key findings that contribute to our understanding of salmon ecology in WRIA 9 are summarized below: Anchor Environmental and Natural Resources Consultants (2004), Berge and Mavros (2001), Brennan and Higgins (2004), City of Seattle Salmon Team (2003), Goetz et al. (2003), Goetz and Jeanes (2004), Hahn and Cropp (2003), Malcom (2002), Natural Resources Consultants, Inc. (2004), Nelson and Boles (2003), Nelson et al. (2004), R2 Resource Consultants, Inc. (2001), Ruggerone and Jeanes (2004), Seiler et al. (2002), Sobocinski (2003), Toft et al. (2004), Weitkamp et al. (2000), Williams et al. (2001). The reader should refer to the source documents for a full and valuable list of findings and detailed information.

This summary section reviews the important elements of these studies to the subwatershed areas defined in other recent WRIA 9 planning documents, namely the Upper Green River (RM 93+ to 64.5, headwaters to Howard Hanson dam), the Middle Green River (RM 64.5 to 32.0, Howard Hanson dam to Highway 18), the Lower River (RM 32.0 to 11.0, Highway 18 to the Black River confluence), the Duwamish River Estuary (RM 11.0 to 0.0, the Black River mouth to Elliott Bay) and the Marine Nearshore (estuarine/marine waters of WRIA 9).

A thorough description of the current state of knowledge regarding the Chinook life cycle use of habitat in WRIA 9 is fully elaborated in the Conceptual Model section of Natural Resources Consultants, Inc. (2004). The conceptual model was developed as a tool to help assist recovery planning and provides guidance for developing research questions. A majority of the information used in model is from WRIA 9 research studies like those noted above. Information from other watersheds is also used to compare with WRIA 9 studies and to make reasonable assumptions regarding Chinook ecology when specific watershed information is lacking. The model (see Natural Resources Consultants, Inc. 2004, Figure 2.) defines and discusses Chinook life history per stage (adult, egg, juvenile) and juvenile trajectory terminology (yearling, fingerling, fry) used in this summary and other efforts that support the Habitat Plan.

5.2. UPPER GREEN RIVER SUBWATERSHED

5.2.1. Juvenile Studies

No recent studies have been conducted describing fish ecology in the Upper Green River subwatershed. However, Tacoma Public Utilities (TPU) and NOAA Fisheries are currently collecting DNA from resident rainbow and cutthroat trout for genetic studies that are intended to provide a better understanding of the current status of these species prior to the reintroduction of anadromous salmonids.

Monitoring studies will be initiated during the beginning phase of joint operation of the TPU headworks dam adult trap and haul facility at RM 61, and the U.S. Army Corps of Engineers' (ACOE) downstream juvenile fish passage facility at the Howard Hanson Dam (HHD). The trap and haul facility will become operational in July 2004, and the downstream passage facility at HHD should be accessible to juvenile salmonids in 2007 (Hickey, pers. com. 2004).

5.2.2. Migration Timing and Fish Size

At present, Chinook adults are not placed upstream of HHD, so natural production does not currently occur in this subwatershed. The Muckleshoot Indian Tribe (MIT) plants approximately 400,000 marked Chinook fry in the upper watershed in late March (Anchor Environmental and Natural Resources Consultants, Inc. 2004). The survival rate of these fish is thought to be very low because of downstream passage problems posed by high river flow during the spring outmigration season, which coincides with reservoir refill (Kerwin and Nelson 2000). Some marked hatchery subyearling Chinook were captured during the spring of 2000 at the WDFW screw trap at RM 34.5 (Seiler 2002). Larger hatchery Chinook juveniles have been observed moving through HHD during the late fall and early winter when the reservoir level is dropped to "run of the river" conditions in preparation for storage of winter flows (Anchor and NRC 2004).

5.3. MIDDLE GREEN RIVER SUBWATERSHED

5.3.1. Natural Juvenile Chinook

One of the few studies directly aimed at assessing juvenile salmonid habitat use was carried out by the ACOE in the Middle Green Subwatershed. The purpose of this study, conducted between1998 and 2000, was to elucidate life history characteristics and salmonid habitat use of the Middle Green River and help HHD managers identify strategies to minimize flow manipulation effects upon salmonids (R2 Resource Consultants, Inc. 2001). Sampling was focused mainly on shallow mainstem lateral habitats (defined as mainstem and off-channel habitats with water depths of less than 1.5 meters. Chinook fry were found to use the mainstem habitats much more than the off-channel habitats. Moreover, in the mainstem, Chinook preferred shallow, low-velocity stream edge areas with ample structural cover. There was a tendency for the smaller, younger, Chinook fry, i.e., those less than 50 mm in length, to initially use shallow areas, and gradually shift into deeper water as they grew. By late March, fry were found in slow-velocity (below 2.0 fps) habitat created by deep scour pools formed by boulders and mats of woody debris. The tendency for smaller Chinook fry to occupy low-velocity, densely vegetated areas along the channel margin, and later, as the fish grew, occupy faster-velocity habitats further from the bankline was also observed in the lower Green River by Koon (pers. comm. 2003). Chinook were also found in off-channel habitats, defined as areas separated from the mainstem through a vegetated island or abandoned flood plain (e.g., wall base channel, old oxbows). These habitats were susceptible to disconnection from the mainstem at flows of less than 850 cfs.

The ACOE study also found that Chinook fry dominated salmonid catches throughout March and early April, and thereafter steadily declined in abundance until June, when Chinook catches became negligible. Downstream at the WDFW screw trap at RM 34.5 a different catch pattern was detected. In 2000, WDFW (Seiler 2002, Figure 4.) found a strongly bimodal pattern of juvenile Chinook outmigration, with one large peak of fry migration from January through March, and a second smaller peak of fingerling outmigration from May through June. This bimodal pattern was also observed with varying ratios of fry/fingerling abundance in 2001 (Nelson and Boles 2003, Figure 18) and 2002-2003 (Nelson et. al 2004, Figures 3-28 and 3-12).

Chinook fry ranging from 35 to 45 mm in length (Table 5.1) represent ocean-type fish that appear to move to the lower river and estuary to rear (Natural Resources Consultants, Inc. 2004). Flows appear to influence the fry/fingerling ratio in any given year, with more fry captured during periods of high winter and early spring flows, when downstream migration is likely to be passive rather than volitional. Nelson et al. (2004) also observed fry movement during moderate flow conditions, which suggests that active migration could also be occurring. The larger, approximately 70-80 mm, natural fingerlings are thought to be more physiologically prepared to enter marine waters and thus tend to spend less time rearing in the lower river and estuary prior to marine residence.

In 2000, WDFW estimated that about two-thirds of the watershed natural juvenile Chinook production occurred upstream of the screw trap due to spawning ground redd distribution information. Malcom (2002) reports similar spawning ground densities for the Green River from 1997 to 2000.

Soos Creek, which enters the right bank of the Green River at RM 33.8 downstream of the WDFW screw trap at RM 34.5, appeared to produce a large amount of fry in 2000 (Seiler 2002; and in 2003 (Nelson et al. 2004). In 2000, WDFW estimated that about 25% of the entire Green River natural Chinook juvenile outmigration (fry plus fingerlings) was from Soos Creek. This high abundance was assumed to result from passage of thousands of adults upstream of the hatchery weir at RM. 0.8. Nelson et al. (2004) also found high numbers of fry in lower Soos Creek in 2003, but a production estimate was not attempted.

5.3.2. Natural Adult Chinook Spawning

As previously mentioned (see Section 3.5.1.3, Current Chinook Spatial Distribution), data from spawning surveys conducted from 1997 to 2002 was used to map redd density in the watershed. About 80 percent of the Chinook redds were found in the Middle Green River mainstem. These redds were from a mix of hatchery and naturally produced adults, with about 60 percent attributed to adults that originated in the Soos Creek Hatchery and Icy Creek Ponds (Anchor Environmental and Natural Resources Consultants 2004).

The accuracy of redd estimation methodologies used in the Green River and in other rivers are currently being assessed by WDFW (Hahn and Cropp 2003) by analyzing the results of a mark-recapture study conducted from 2000 to 2002. By comparing the results of traditional redd-count method and a mark-recapture method simultaneously applied in 2001, WDFW concluded that the traditional redd-count method results in up to a nearly 3-fold underestimation of the actual natural adult escapement. Analysis of potential disparities resulting from application of these two methods in other years indicates less dramatic differences--a 1.69 and 1.08 fold increase in escapement based on the mark-recapture method, but the overall average historical underestimation of 50 percent is still quite significant. Precise escapement estimation will be necessary for assessing the viability and recovery of the natural Green River Chinook stock.

5.3.3. Hatchery-Natural Chinook Interactions

The Middle Green River Subwatershed is the epicenter of salmonid hatchery production in WRIA 9. In the spring of 2003, about 3.7 million Chinook and 3.3 million chum, coho and steelhead trout originating from hatcheries were released into WRIA 9 (Anchor Environmental and Natural Resources Consultants 2004). Since the downstream end of the Middle Green Subwatershed lies near the confluence of Soos Creek, where most of the Chinook juveniles are released, the primary interaction between natural and hatchery fish upon adult return is within this area. As noted by Anchor Environmental and Natural Resources Consultants (2004), the high adult hatchery stray rate into the river could be altering the genetic makeup of natural Chinook. When queried about the magnitude of a maximum allowable stray rate into rivers, NMFS staff stated that a stray rate even as low as five percent of hatchery fish onto natural spawning grounds may not be acceptable (Grant 1997).

Table 5.1 displays the current generalized timing and size range of Chinook as they migrate from the Middle Green River subwatershed into downstream areas.

Table 5.1. Generalized Juvenile Chinook Timing and Size While Migrating out of the Middle Green River Sub-watershed

Natural Chinook			Hatchery Chinook	
Life history types	**Peak time**	**Size (fork length)**	**Peak time**	**Size (fork length)**
Fry	January-March	35-45mm	none	N/A
Fingerlings	May-June	70-80mm	late May-early June	About 85mm
Yearlings	no info	no info	May	About 150-180mm

source: Nelson et al (2004) and Seiler (2002).

5.3.4. Bull Trout Information

Although there are no recent studies of bull trout habitat use of WRIA 9, several recent captures of adult bull trout near the mouth of Newaukum Creek, one of which occurred in February, have been reported (Berge and Mavros 2001; Goetz and Jeanes 2004). A sport fisherman at approximate RM 33.8 also captured two adult sized bull trout in October 2001 (pers. com. Hans Berge). Due to these bull trout reports, Newaukum Creek and the Green River mainstem upstream from the Newaukum Creek confluence, including the Upper Green subwatershed, have been targeted for future bull trout surveys (Berge and Mavros 2001) in order to investigate the possible existence of a self-sustaining bull trout population in WRIA 9.

5.3.5. Other Fish Species Information

Salmonid species reported from the catch of R2 Resources Consultants (2001) in the Middle Green was composed of juvenile rainbow/steelhead trout (35%) followed by coho (29%), Chinook (22%) and chum (13%) salmon. The remaining salmonid composition was cutthroat trout (0.2%), mountain whitefish (0.1%), and pink and sockeye salmon (<0.05%). Non-salmonid catch, in order of decreasing capture frequency were: coast range and mottled sculpin; Pacific lamprey; three-spine stickleback; longnose dace; large scale sucker; shorthead sculpin; redside shiner, and brook lamprey.

Chinook dominated the catch throughout March but chum and coho salmon began to emerge in March and composed the majority of the catch by April and May (R2 Resources Consultants 2001). Cutthroat and rainbow/steelhead trout started to emerge in late May and dominated the catch by June. By July, the catch was composed entirely of rainbow/steelhead trout and coho fry. R2 Resources Consultants (2001) found the yearlings (primarily coho and cutthroat) to be associated with off channel habitats containing complex woody debris structures.

Unlike Chinook, large numbers of unmarked hatchery coho and chum salmon juveniles are released into the Middle Green. For example, in 2003 about 1.5 million coho and 1.2 million chum were released (Anchor Environmental and Natural Resource Consultants 2004). Of the 2.7 million total salmon, only 46,000 (all coho) were marked with an adipose clip. This leaves little confidence for determining natural or hatchery origin when coho and chum are collected in research efforts downstream.

5.4. LOWER GREEN RIVER SUBWATERSHED

5.4.1. Natural Juvenile Chinook

Little information regarding Chinook ecology in the Lower Green River subwatershed was found during the reconnaissance phase of the WRIA 9 planning effort (Kerwin and Nelson 2000). Therefore, Chinook use of the lower river was identified as a priority data gap. To address this gap, the WRIA 9 Juvenile Salmonid Survival Studies (JSSS) were initiated in 2001 (Nelson and Boles 2003), and expanded in 2002 to include the Duwamish River, and in 2003 to include Elliott Bay (Nelson et. al. 2004). In three years these studies concentrated on gathering information about the timing, growth rates and relative abundance of hatchery and naturally-produced juvenile Chinook. The findings presented below represent the outcome of the JSSS unless otherwise noted.

Natural Chinook were found to pass through the Lower Green River quickly (hours to days), from late winter to late summer with peaks coinciding closely with those in the Middle Green Subwatershed (Table 5.2). Flows seem to play an important role in the residence time within this reach. It appears that flood control facilities (e.g., riprap revetments) have severely limited the ability of Chinook to find refuge during high flows and as a result, they may be prematurely flushed downstream to the estuary. River flows in 2001 were unusually low during the winter and early spring, and it appears that a higher proportion of fry may have reared in the Middle and Lower Green River compared to the proportions of fish that reared there during the same time period in 2002 and 2003 (Nelson et al. 2004).

5.4.2. Hatchery-Natural Chinook Interactions

In recent years, about 3.5 million hatchery Chinook fingerlings were released annually in WRIA 9. These fish typically travel through the Lower Green at a time when smaller and much less abundant natural fingerlings are present, thus the more abundant and larger hatchery fish may prematurely force natural fish to the estuary. As a result of such interactions, hatchery fish likely have a competitive advantage (at a minimum, due to fat reserves) over their natural conspecifics if the food supply is limited.

Table 5.2. Generalized Juvenile Chinook Timing and Size While Migrating out of the Lower Green River Subwatershed

Natural Chinook			Hatchery Chinook	
Life history types	Peak time	Size (fork length)	Peak time	Size (fork length)
Fry	January-March	35-45mm	None	N/A
Fingerlings	May-June	70-80mm	late May–mid-June	80-85mm
Yearlings	Feb-May	83*-130mm	May	130-150mm

* One 83 mm Chinook captured was at RM 13 on 2/16/03. Source: Nelson et al. (2004).

5.5. DUWAMISH RIVER ESTUARY

5.5.1. Natural Juvenile Chinook

Several year classes of Chinook (fry, yearlings, and possibly two-year-old fish) were found in the Duwamish from January to September from 2002 to 2003 (Nelson et al. 2004, Goetz et al. 2003, Ruggerone and Jeanes 2004). Two peaks in abundance were also apparent in the estuary; the first, composed of fry, was observed from late February to early March, and the second for fingerlings, occurred between mid-May and mid-June. In 2002 and 2003, consistently abundant catches of subyearlings were captured at RM 5.5 and 6.5, which has been postulated to be a critical estuarine transition zone where the river and salt wedge initially mix, throughout the outmigration period (January-June). This transition zone is also where the river widens, velocities decrease, and estuarine mudflats begin to appear. The exact boundaries of the existing transition zone have yet to be defined and future research is being planned to refine its location in the Duwamish River. A much greater expanse of this habitat was historically available closer to and within Elliott Bay prior to regular dredging, reduced freshwater flow from river diversions and extensive filling of historic intertidal areas in the Duwamish River and Elliott Bay. The mixing zone was vastly reduced in size and moved upstream to its current location. Dredging for maintenance of navigation now leaves only a thin margin of tide flats along the shoreline with an artificially deepened central channel from about RM 5.0 to Elliott Bay. The one exception to these narrow slices of intertidal habitat is at Kellogg Island (RM 1.0-1.5). According to the City of Seattle Salmon Team (2003), Kellogg Island has a densely vegetated riparian zone and intertidal wetlands that represent a majority of the remaining intertidal wetlands in the Duwamish Estuary (Simenstad et al. 1991). Although the habitat surrounding Kellogg Island visually appeared to be conducive for rearing, catches there were invariably much lower than at the transition zone (Nelson et al. 2004). Thus it appears that the Chinook actively migrate towards the marine nearshore once they leave the transition zone and spend relatively less time at Kellogg Island.

Natural fry marked at the trap in lower Soos Creek in February and March, 2003 were found in the transition zone relatively soon, one to 31 days after release (Nelson et al. 2004), and may have reared in this area to fingerling size before migrating out to Elliott Bay during the outmigration peak in June (Table 5.3). This long-term scenario would constitute an estuarine residence time of about five months, much longer than commonly believed. From observing peak catch data in 2002 and 2003, most natural fingerlings appear arrive in the estuary in May to acclimate and feed for several weeks (possibly up to 3

months), before departing to marine waters. Nelson et al. (2004) reported that Chinook growth rates in the Duwamish estuary in 2003 were initially steady, but increase rapidly to approximately 0.44 to 0.54mm/day from April through June, except for a three week period from mid May to early June when hatchery Chinook occupied the area. During the time of hatchery Chinook residence, natural growth rates dropped about 75% to just 0.13mm/day, indicating the existence of a juvenile density-dependent depression in growth. The same pattern was seen in 2002, but was less pronounced, possibly due to the fact that fewer sampling events were conducted.

5.5.2. Hatchery-Natural Chinook Interaction

In 2003, release of over three million hatchery Chinook coincided with a time of high natural Chinook abundance in the Duwamish estuary. As a result, it appears that the growth rate of natural Chinook was substantially reduced, and these fish may have been physically displaced as well. This phenomenon was apparent in the transition zone (Nelson et. al 2004), and in restored off-channel estuarine habitats (Ruggerone and Jeanes 2004). These results suggest that there is a shortage of available food and habitat capacity as a result of competition between hatchery and natural Chinook in the estuary, especially in the transition zone. Ruggerone and Jeanes demonstrated that restoration of large amounts of off-channel habitat is necessary to have a measurable effect. This finding is based on an estimate that only 0.16% of the 3 million hatchery Chinook, and 0.16 to 0.33% of the natural subyearling Chinook population used the five off-channel restoration sites these authors sampled in the Duwamish estuary in 2003.

Table 5.3. Generalized Juvenile Chinook Timing and Size During Downstream Migration Through the Green/Duwamish Estuary Sub-watershed

Natural Chinook			Hatchery Chinook	
Life history types	**Peak time**	**Size (fork length)**	**Peak time**	**Size (fork length)**
Fry	Feb-March	40-50mm	None	N/A
Fingerlings	May-June	78-85mm	mid-May–mid-June	80-90mm
Yearlings	late March-May	110-145mm	May	175mm

source: Nelson et al. 2004

5.5.3. Bull Trout Information

Since 2000, nine sub-adults (mean size 290 mm) and one adult (585 mm) have been captured in the Duwamish River. The large adult was captured twice on May 15, 2003 near Kellogg Island (RM 1.0); the sub-adults came from the transition zone (RM 5.5) in August 2000 and September of 2000 and 2001 (Goetz and Jeanes 2004). Informal reports have also been made of sports fisherman catching char, probably bull trout, near RM 3.0 while trolling for coho salmon in the fall of 2002.

5.5.4. Other Fish Species Information

Chum followed by Chinook were the two most abundant salmonids captured in the Duwamish in both 2002 and 2003 (Nelson et al. 2004). In 2003, chum fry represented 59 percent of the total number of the salmonids captured and the highest catches occurred from March16 to May 24. Chinook (hatchery and

natural) constituted 25 percent of the catch, 6 percent were coho, 0.2 percent were steelhead, and less than 0.1 percent were pink fry and cutthroat trout.

In 2003, chum salmon outnumbered all other fish species, and in 2002 shiner perch were most numerous. The Duwamish River had the greatest fish species richness of the subwatersheds sampled with a total of 24 species collected (e.g., salmonids, flatfish, gunnels, tom cod, herring, sculpins, surf smelt, snake prickleback, three spine stickleback).

5.6. MARINE NEARSHORE (INCLUDING ELLIOTT BAY, MAINLAND, AND VASHON/MAURY ISLANDS)

5.6.1. Natural Juvenile Chinook

Most of what was known previously about juvenile Chinook salmon use of the marine nearshore environment came from studies conducted near the mouths of estuaries and sporadic sampling of Puget Sound shorelines outside of WRIA 9. In order to fill data gaps and develop an improved understanding of juvenile Chinook early life history characteristics in the marine environment, beach seine surveys were conducted in 2001 and 2002 along several marine shorelines in WRIA 9 including the mainland from Alki Point to Federal Way, and segments of the Vashon/Maury Island shoreline (Brennan and Higgins 2004). These surveys complemented those conducted in the Green River, Duwamish estuary and Elliott Bay surveys conducted from 2001 through 2003.

In 2003, beginning in late January, natural Chinook fry were found along several Elliott Bay shorelines and at the mouth of the Duwamish River (Nelson et al. 2004). After early February, the fry catch declined until peaking again from mid-May to late June, coinciding with the fingerling outmigration from the Green/Duwamish River. Sampling along shorelines outside of Elliott Bay in May of 2001 and 2002 revealed that juvenile Chinook were present when sampling began, peaked in abundance (i.e., the highest catch per unit of effort [CPUE]) in June, followed by a secondary peak in late July, and continued to appear in the sampling catches into December. Juvenile Chinook were captured throughout the nearshore study area, and there were no significant differences in catch rates between mainland and island sampling sites. There were also no significant differences in catch at various tidal elevations, indicating that juvenile salmonids move up and down along with shoreline with the tide, using shallow water habitats. The use of shallow water habitats was also observed in a study conducted by the University of Washington (Toft et al. 2004). Based on these studies and previous assessments (e.g., Williams et al. 2001), Chinook salmon appear to occupy the marine nearshore environment at any time of the year.

An analysis of the distribution patterns of juvenile Chinook documented in these studies showed some remarkable results. Although juvenile Chinook appear to be shoreline oriented, they are quite broadly distributed, and readily cross the open waters of Puget Sound. Furthermore, juvenile Chinook salmon do not simply leave the Green/Duwamish River system and head north on their way through Puget Sound to the open sea. Based on recaptures of coded wire tagged fish, Green River Chinook appeared to disperse into Puget Sound around mid-June, at around the same time coded wire tagged fish from other river systems increased in the catch (Nelson et al. 2004). Outside of Elliott Bay, juvenile Chinook from the Green/Duwamish were found in higher numbers south of Elliott Bay, compared to catches of these fish at northern sampling sites. Juvenile Chinook were also captured along the shoreline of Vashon and Maury Islands, which have no Chinook-bearing streams. These results indicate that oceanographic influences (e.g., winds and surface currents) may play a significant role in their distribution within nearshore waters. In addition, coded wire tagged juvenile salmonids recaptured within nearshore areas of WRIA 9 originated from 16 different hatcheries and nine different WRIAs, illustrating the level of stock mixing and the importance of the WRIA 9 nearshore to multiple stocks of Chinook.

The first detailed examination of juvenile Chinook feeding habits along marine shorelines of the Puget Sound (Brennan and Higgins 2004) revealed a surprisingly large component of terrestrial insects in their diet (50% numerically overall), with an even higher seasonal component (~80%) of terrestrial insects by weight for one size category. Similar results were found by Toft et al. (2004) along Seattle's marine shoreline. Over the course of the year, juvenile Chinook diets are composed of diverse prey that are of benthic, pelagic, and terrestrial origin. The prey composition varies seasonally and with fish size, with smaller fish feeding primarily on epibenthic and pelagic organisms and the largest size category of fish (>150 mm) feeding primarily on other fishes (e.g., herring and sand lance). As is the case with regard to their spatial distribution patterns, juvenile Chinook diets are quite diverse, and their composition varies with life history stage, season and habitat occupation, underscoring the importance of maintaining a diverse array of nearshore habitat types. Sobocinski (2003) shows that one of these habitat types, the supratidal zone, is impacted by shoreline armoring that decreases abundance and taxa richness in both infaunal invertebrate and insect assemblages.

Toft et al. (2004) investigated the abundance and behavior of juvenile salmon and other fishes at sites with different shoreline modifications (e.g., bank armoring, overwater structures) along Seattle's marine shoreline in 2003. Through the use of enclosure nets and snorkel surveys, the study found that substrate type and slope are the most influential factors for fish densities when shoreline modifications only extend into the upper intertidal zone. However, shoreline modifications extending into subtidal areas have the largest effect on fish densities and behaviors by truncating the shallow water zone. In the absence of shallow water habitat, Toft et al. (2004) found that juvenile salmonids were forced into occupying deep water areas and exhibit a higher amount of schooling behavior. In addition, juvenile salmon avoided areas under overwater structures.

5.6.2. Hatchery Chinook Interaction

Given the temporal and spatial use of the marine nearshore and apparent consumption of the same types of food resources (Brennan and Higgins 2004), it is apparent that hatchery and wild fish compete for the same resources. While little is known about resource limitations, partitioning, or potential behavioral changes resulting from these interactions, it is likely that wild juvenile Chinook are at a disadvantage. In the studies by Brennan and Higgins (2004) and Nelson et al. (2004), wild Chinook were smaller in size, occurred in significantly lower numbers, and apparently competed for the same spatial and dietary resources as their hatchery counterparts during the same time periods.

5.6.3. Bull Trout Information

A recently released draft report on bull trout ecology in the nearshore (Goetz and Jeanes 2004) states that "[B]ull trout in the Puget Sound can undertake rapid, directed migrations that may exceed 250 km using the nearshore marine shorelines as pathways." The only direct data in this report regarding the utilization of WRIA 9 by bull trout was a single fish captured at Lincoln Park on April 11, 1998. However, due to the highly migratory behavior of these fish, many important inferences for WRIA 9 can be drawn from data collected in other nearshore areas. Especially important are the bull trout diet studies that show a prevalence of bull trout prey species (e.g., smelt, herring, sandlance and shiner perch) that depend on the marine nearshore for spawning habitat.

5.6.4. Other Fish Species Information

During the Brennan and Higgins (2004) study period from 2001 to 2002, nine salmonid species were represented in the cumulative catch (Chinook, coho, chum, pink, sockeye, and Atlantic salmon, steelhead, cutthroat and Bull trout). Chum salmon were the most abundant, followed by pinks, chinook, coho,

cutthroat, sockeye, and steelhead. Only two bull trout (one caught during test seining) and one Atlantic salmon were captured during this study.

Pink salmon abundance peaked in April and they were absent from the catch after May. Chum salmon abundance was also high in April and May, but dropped off dramatically after July and into October. Coho abundance also peaked in May and they continued to be present in the catch into October. Coho were caught at a significantly higher level at sites with attached submerged aquatic vegetation, especially eelgrass and for sites with gravel substrates.

In both years of Brennan and Higgins (2004), coho and cutthroat diets were analyzed for composition. Fishes, especially larval and juvenile sand lance, dominated coho salmon diet (by weight). Fish dominated cutthroat trout diets in both years except for those in the 150-199 mm size class, in which terrestrial/riparian insects were abundant.

5.7. LIMITING FACTORS AND VIABILITY PARAMETERS ADDRESSED BY THE RESEARCH STUDIES

Numerous habitat factors limiting salmon recovery in WRIA 9 were described in Kerwin and Nelson (2000) and Williams et al. (2001). Although these reports did not rank the factors, primary ones are: altered hydrology (river diversions and withdrawals, altered flow regime); hydromodifications (dredging/filling, channeling, bulkheads/revetments, dams, over-water structures); interruption of sediment transport processes; loss of natural riparian conditions (including wetlands); fish passage barriers and water quality degradation. Although many of the studies summarized in this section were not designed to directly assess limiting factors, the studies do substantiate timing factors previously addressed and elevates our awareness of the impact of hatchery practices upon natural salmon survival.

WRIA 9 embraced the viable salmonid populations (VSP) approach, which provides another perspective on salmonid recovery to compliment the traditional limiting factor assessment. It tends to focus more on the resilience of salmonid populations to adapt to changing conditions. A few important findings and how the studies relate to habitat limiting factors and viability parameters (e.g., abundance, spatial structure, productivity, and diversity) are given below.

Intensive channeling and bank armoring (hydromodification) of the Lower Green River for flood control and loss of shallow, low velocity habitat is identified (Nelson et al. 2004) as a probable cause for rapid movement of juvenile Chinook through this area. Additional rearing habitat, especially during high flows may allow Chinook to achieve a larger size on entry into the estuary, thereby increasing their survival and enhancing the productivity, diversity and spatial structure.

Dietary analysis of juvenile salmon, especially Chinook, in the marine nearshore (Brennan and Higgins 2004) shows the dependence of salmon upon terrestrial insects and amplifies the importance of vegetated riparian areas in prey production. Forage fish (e.g., sandlance and herring) another important food item, especially for larger juveniles, depend on the intertidal areas for spawning. Both the intertidal and supratidal nearshore zones have been extensively modified in WRIA 9 leading to reduced habitat productivity.

Competition with hatchery fish was an issue in almost every subwatershed. Millions of hatchery salmonids, including about 3.5 million Chinook fingerlings are released each year at a time when natural Chinook abundance is peaking in the estuary and lower river. The natural and hatchery fish are captured together after hatchery releases in May from the Lower Green through the Marine Nearshore Subwatershed (Nelson et al. 2004, Brennan and Higgins 2004) implying competition for similar resources from the onset of out migration. Competitive interaction was shown in the possible premature

displacement of natural fish from their habitats (Nelson et al. 2004, Ruggerone and Jeanes 2004) and decreasing Chinook growth in the Duwamish. The decreased growth rate reported in 2003 (Nelson et al. 2004) is affected by the limited food supply partly a result dredging and filling of the historical intertidal mudflats and wetlands in the Duwamish estuary. Hatchery fish were also reported to be larger at all locations (Nelson et al. 2004, Brennan and Higgins 2004), which imply a competitive advantage. The hatchery fish presence inherently reduces available habitat to natural fish thereby reducing the productivity of the remaining habitats. Hatchery fish also interfere with natural diversification through the domestication of the natural stock by hatchery adults straying onto the natural spawning grounds (Anchor Environmental and Natural Resources Consultants 2004).

SECTION 6 – FUNCTIONAL LINKAGES BETWEEN HABITAT AND SALMONID POPULATIONS

6.1. PURPOSE OF THE EVALUATION

The functional linkages evaluation is a synthesizing step in the sequence of technical tasks that support salmon habitat planning in WRIA 9. Functional linkages are defined here as qualitative and quantitative relationships between habitat quantity and quality and the four parameters of Viable Salmonid Populations: abundance, productivity, genetic and life history diversity, and spatial structure. As described below, the functional linkages evaluation included the development of conservation hypotheses about the types of actions that will benefit Chinook populations. The work described and referenced in this section provides a basis for the habitat management strategies, management actions, and the adaptive management program that will appear in the Habitat Plan.

6.2. ECOLOGICAL SYNTHESIS APPROACH (SALMON ECOLOGY AND CURRENT VERSUS HISTORIC HABITAT APPROACH)

The WRIA 9 Technical Committee determined that Task 6 of the Strategic Assessment, the functional linkages evaluation, would be conducted in two phases. Phase 1 would determine the best way to link quantity and quality of habitat to salmon abundance, productivity, and diversity in a spatially explicit way. Phase 2 would involve application of the analytical tool or model(s) selected in Phase 1.

Following a scoping process with Technical Committee members, King County contracted with Anchor Environmental to prepare the Phase 1 report. The report compares and contrasts a number of analytical models or tools and discusses the opportunities and issues associated with their application in WRIA 9. Some of the tools are built on statistical relationships among parameters and some are scientific models, built from a general understanding of how ecosystem processes work and the interaction of variables. Seven approaches were selected for review and comparison based on their stated purpose, history of use, and potential for use in WRIA 9:

- Ecosystem Diagnosis and Treatment (EDT),
- EDT-Light,
- SHIRAZ,
- Qualitative Habitat Assessment (QHA),
- Salmonid Watershed Assessment Model (SWAM),
- Cumulative Risk Initiative (CRI), and
- Synthesis of best available science related to salmon ecology and historic versus current habitat, which was named the Ecological Synthesis Approach.

The Phase 1 report, *Toward An Understanding Of Functional Linkages Between Habitat Quality, Quantity And Distribution And Sustainable Salmon Populations: A Review Of Analytical Approaches And Recommendations For Use In WRIA 9* (Anchor Environmental and Natural Resources Consultants 2003), concluded there is no obvious choice, nor a choice upon which WRIA 9 should depend exclusively. However, two options were recommended for further consideration - SHIRAZ by itself or

coupled with other statistical tools such as CRI, or the Ecological Synthesis Approach. The Technical Committee reviewed the Phase 1 report and chose the Ecological Synthesis Approach. The ability to provide information that would be useful in the development of habitat management strategies and actions for the Habitat Plan was an important consideration. The Technical Committee concluded that the Ecological Synthesis Approach, in concert with adaptive management and monitoring plans (which may include application of other scientific or statistical tools), could meet the needs of WRIA 9.

The Ecological Synthesis Approach does not use a single model, but relies on information from as many sources as possible, including information on current and historical habitat quantity and quality and fish use, limiting factors analyses, statistical models, and scientific models as available. It provides a series of conservation hypotheses to guide the development of habitat management strategies and actions. In contrast to the other models reviewed, the Ecological Synthesis Approach is a less structured approach that does not have an underlying framework or a series of *assumed* functional relationships upon which decisions are made. Instead, it is a practical approach based on empirical observations of how Chinook salmon currently use habitats in WRIA 9 in the context of current versus historical habitat. Conservation hypotheses about fish use and habitat, based on the best available science, will be tested though quantitative monitoring projects.

The Ecological Synthesis Approach draws upon a number of technical resources in WRIA 9 regarding the life history of salmonids in relation to their current and historical habitat. As part of the Strategic Assessment, Ruggerone and Weitkamp (2004) have developed a conceptual model of the life history of natural Green River Chinook salmon. This model is largely based on existing information and recent sampling of juvenile Chinook salmon by King County (Nelson et al. 2004), Army Corps of Engineers (2000), the University of Washington, the Port of Seattle, and various consultants. Building on the science of the Habitat Limiting Factors and Reconnaissance Assessment (Kerwin and Nelson 2000), the Strategic Assessment includes historical and current conditions assessments (see Sections 2 and 3 of this report and related documents) and a comparison of historical and current habitat conditions (Section 4). The Reconnaissance Assessment of the State of the Nearshore Ecosystem (Williams et al. 2001) and a subsequent evaluation of salmonid species composition, timing, distribution, and diet in the Nearshore (Brennan et al. 2004) provide additional information on fish populations and habitat.

For example, one current hypothesis is that the upper end of the estuary where fish initially reach marine waters is a key habitat area for juvenile Chinook salmon, especially fry migrants that leave the Middle Green River during January through March. High densities of juvenile Chinook salmon have been observed here during multiple years (Nelson et al. 2004). Rearing habitat could be constructed and fish use (numbers, residence time, growth) could be monitored. This approach is currently used by Goetz et al. (2003), who estimated fish use, residence time, and percentage of the population that utilized restored off-channel habitats in the Duwamish estuary.

Figure 6.1, based on the WRIA 9 Habitat Plan Work Plan and Schedule, shows how WRIA 9 sought to enhance the application of the Ecological Synthesis Approach with involvement of others, such as the Puget Sound Technical Recovery Team (TRT) appointed by NOAA Fisheries, Shared Strategy, and Co-Managers. The WRIA 9 Steering Committee and invited guest, Bill Ruckelshaus (Salmon Recovery Funding Board Chair, Shared Strategy Development Committee Member), reviewed the process at the September 11, 2003 meeting and it was favorably received. WDFW did participate in the process via its staff liaison to the WRIA 9 Technical Committee and the Steering Committee but did not provide the results of its EDT modeling. Tribes were invited to participate in the evaluation and workshops (and kept informed throughout the process), but did not participate directly in the process.

Green/Duwamish and Central Puget Sound Watershed (WRIA 9) Salmon Habitat Planning

Key Points in the Process for Involvement of Puget Sound Technical Recovery Team (TRT), Shared Strategy and Others

OBJECTIVES:

- Obtain TRT/Shared Strategy validation for the WRIA 9 process while offering an alternative approach
- Effectively engage the TRT and others in the WRIA 9 process
- Meet NOAA Fisheries requirements for regional recovery and thereby provide jurisdictions the highest possible level of assurances

COMPELLING ATTRIBUTES:

- Commitment to Viable Salmonid Populations analysis
- "Salmon Ecology and Current vs. Historic Habitat Approach" aka "Ecological Synthesis Approach" (Anchor 2003) - a practical approach to evaluation of habitat conditions and fish population response (functional linkages)
- Development of conservation hypotheses to guide protection, rehabilitation and enhancement
- Integration of Nearshore analysis and planning
- Ongoing juvenile chinook salmon research and monitoring
- Includes development of monitoring and adaptive management plans - hypothesis testing for fish use of restoration projects through quantitative evaluation
- Addresses hatchery and wild fish interactions
- Possible application of ecological economics
- Offers an example of a more urbanized/industrialized watershed
- Embodies all issues that face Puget Sound salmonid populations (historic alterations, land management issues, complex flow issues, hatchery and harvest issues, multiple jurisdictions and stakeholders)
- A governance structure that supports implementation

WRIA PROCESS (WITH TECHNICAL WORK AS THE FOCUS):

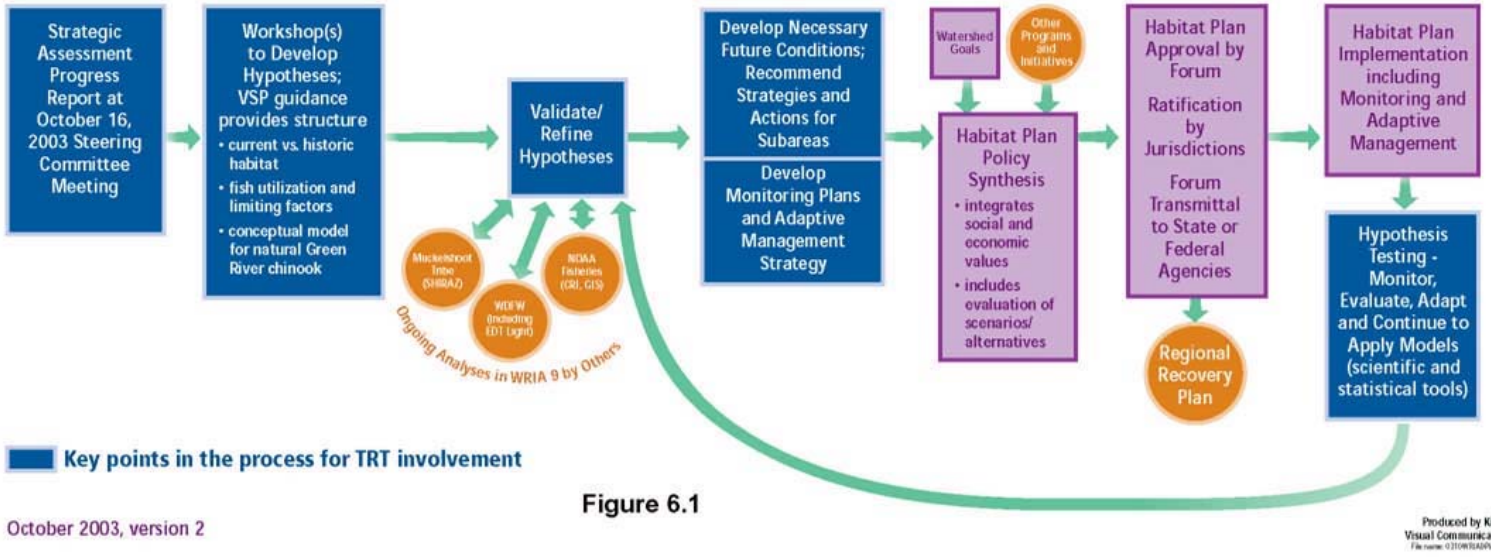

Figure 6.1

October 2003, version 2

Produced by King County WLR Visual Communications and Web Unit

The flow chart emphasizes the technical aspects of the WRIA 9 Habitat Planning process, beginning with a Strategic Assessment progress report in October 2003. Workshops to develop conservation hypotheses were held in April and May 2004 to validate and refine the hypotheses. The conservation hypotheses are the primary work product of the functional linkages evaluation using the Ecological Synthesis Approach.

6.3. CONSERVATION HYPOTHESES AND RATIONALE

The conservation hypotheses are not traditional scientific hypotheses that are stated in a null sense to be statistically accepted or rejected. Rather, they are an estimate of how improvements in habitat conditions and habitat-forming processes will lead to changes in the four VSP parameters: abundance, productivity, spatial structure, and genetic and life history diversity.

The draft Phase 2 report, *WRIA 9 Conservation Hypotheses, Functional Linkages Phase 2* (Anchor Environmental and Natural Resources Consultants 2004), presents the conservation hypotheses developed by the consulting team, the Technical Committee and other regional participants. The Technical Committee sponsored workshops, supported by the Anchor Environmental consulting team, to bring scientists together. (Workshop summaries are included in the draft Phase 2 report.) The group relied on past research from within the system, information from other systems within Puget Sound and the range of Chinook salmon, and recent studies within the watershed related to historical and current habitat conditions, fish use and factors that limit the productivity of fish populations.

The draft Phase 2 report includes a description of the process, a summary matrix of hypotheses and their rationale, and guidelines for research, monitoring and evaluation and adaptive management. Expanded descriptions of conservation hypotheses were prepared by Technical Committee members and are provided as an appendix.

The final list of 32 conservation hypotheses included seven that were identified in the basin-wide category, five in the Nearshore, four in the Duwamish estuary, four in the Lower Green River, six in the Middle Green River, three in the Upper Green River, and three that identified non-habitat issues.

- Watershed-wide - The hypotheses contemplated a range of actions, including improved water quality, restored riparian zones, improved tributary conditions and access, high and low flow modifications, low impact development, and reduced armoring and filling.
- Upper Green River - Restoring Chinook salmon and bull trout access to habitat above Howard Hanson Dam, and restoring and protecting spawning and rearing habitat were the primary hypotheses.
- Middle Green River - The hypotheses included protection and creation of refugia, restoration of sediment recruitment, restoration of spawning habitat in Soos and Newaukum creeks, increased emphasis on low impact development, improved groundwater recharge, and establishing fish access above the Tacoma Headworks.
- Lower Green River - The hypotheses focused on high flow/velocity refuge, restoration of sediment recruitment, protection of groundwater recharge via old White River channel, and improved fish passage at the Black River pump station.
- Duwamish - The hypotheses included protection and restoration of vegetated shallows and marsh habitats, improved sediment quality, an enlarged freshwater to saltwater "transition zone," and protection and restoration of refugia.
- Nearshore/Elliott Bay - The hypotheses focused on improving sediment quality, protection of vegetated shallows, protection and restoration of sediment transport, protection of forage fish spawning habitat, and protection and restoration of pocket estuaries.

- Non-habitat - These hypotheses address hatchery reform, modification of harvest techniques to include live capture gear, and reduction in the harvest of salmon prey items, e.g., Dungeness crab and forage fish.

Table 6.1, summarizing the conservation hypotheses and rationale, is an excerpt from the draft Phase 2 report. The types of actions associated with each of the conservation hypotheses are also included in Table 6.1. These actions can be broadly grouped into four habitat management strategy directions -- protection, restoration, rehabilitation, and substitution (NRC 1992). As summarized by the TRT, the certainty of success in moving the population closer to the desired state of viability decreases as one moves from protection to substitution (TRT and Shared Strategy 2003). This means that protecting a habitat process or feature that is naturally functioning is more certain than artificially constructing a habitat feature where there is little opportunity to restore a habitat forming process. The latter may function for some brief period of time, but is not likely to be sustainable.

Table 6.1. Conservation Hypotheses

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
HABITAT-BASED CONSERVATION HYPOTHESES											
Applicable to entire WRIA	All-1	---	Protecting and improving water quality (e.g., temperature, dissolved oxygen, turbidity, and chemical contamination conditions) by addressing pollution sources will enhance habitat quality and lead to greater juvenile salmon growth, disease resistance, and survival. Improved water quality will also enhance survival of adult salmon, incubating salmon eggs, and salmon prey resources, such as forage fish.	• Retrofit stormwater detention and treatment facilities in urban and industrial areas • Reduce CSO discharges • Repair/replace failing septic systems • Remove creosote treated wood • Protect groundwater sources that provide cold water, e.g., connection to White River and Deep/Coal Creek subbasins • Protect tributaries and springs that provide cold water, particularly in the lower and middle river sections • Manage agricultural runoff to reduce nutrient and waste loading to streams • Restore freshwater and saltwater marshes that reduce runoff rates • Reduce non-point air pollution • Education • Implement road setbacks	• All-2 • All-3 • All-6 • Low-3	• All lifestages	• Improve egg survival (both salmon and forage fish) • Increase food availability • Expand physiological refuge • Enhance resistance to disease • Enhance migration corridor • Enhance rearing habitat • Improve adult homing and upriver migration survival • Pollution abatement • Soil stability • Erosion control	• Abundance • Productivity	• Degraded water quality reduces the production of prey items consumed by juvenile salmon. • Enhanced prey availability will enhance growth and survival. • Degraded water quality influences juvenile salmon fitness and disease resistance. • Degraded water quality influences adult homing and upriver migration survival. • Improved water quality will contribute to adults having more energy for gamete development, upriver migration, and spawning that will lead to higher egg incubation survival.	• Powell et al. (2002) • Arkoosh et al. (1999) • Stein et al. (1995) • WDOE (2002)	• Rehabilitate/ Low-Moderate • Preserve / High

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
Applicable to entire WRIA	All-2	---	Protecting and improving riparian zone conditions by adding native riparian vegetation will enhance habitat quality by improving water quality, stabilizing streambanks, providing overhanging vegetation and large woody debris (LWD), and contributing organic matter, nutrients, and terrestrial prey items, thereby leading to greater juvenile salmon growth and higher survival.	• Restore native vegetation, including overhanging vegetation, in marine nearshore and freshwater riparian areas to provide shade, reduce runoff rates, and reduce contaminants entering waterways with functional buffers • Restore native vegetation in riparian corridor that improves water quality and contributes organic matter and terrestrial prey items • Reconfigure levees and bulkheads, particularly in the Lower Green River and marine shorelines, to allow restoration of riparian vegetation in more natural proximity to water to improve likelihood of vegetation survival and functional contribution to salmon habitat • Plant riparian vegetation to improve long term potential for LWD recruitment • Provide riparian vegetated buffers • Remove/prevent armoring and fill • Maintain or restore riparian corridor conditions in tributaries • Allow flood events for germination and LWD recruitment • Add LWD in mainstem river and tributaries to provide habitat complexity, organic matter, and high-energy refuges	• All-1 • All-5	• Juvenile foraging/rearing • Juvenile migration • Adult holding • Adult spawning	• Increase food availability • Improve predator refuge • Expand physiological refuge • Expand high energy/flow refuge • Enhance migration corridor • Enhance rearing habitat • Improve spawning ground quality for salmonids as well as forage fish in nearshore areas • Pollution abatement • Soil stability • Erosion control • Wildlife habitat • Organic/nutrient inputs • LWD inputs/habitat structure • Microclimate • Prey production	• Abundance • Productivity	• Improved riparian conditions will enhance prey availability • LWD recruitment will enhance pool and spawning habitat • Enhanced prey availability will enhance growth and survival • Juvenile salmon will use shade of improved riparian corridor and eventually LWD provided from riparian vegetation will provide refuge from fish and bird predators • Forage fish egg survival is higher on shaded beaches • Salmon utilization of tributaries will increase with improved conditions	• Brennan and Higgins (2004) • City of Seattle Marine fish report 2004 • Penttila 1998. • Rice 2003 • Draft report for Shared strategy on bull trout due May 2004 (diet of forage fish) • Beschta et al. (1987) • Williams et al. (2001) • Kerwin and Nelson (2000) • Williams et al. (1997) • Platts (1993) • Cummins (1974) • Chapman and Demory (1963)	• Restore / Moderate • Rehabilitate/ Low-Moderate • Preserve / High
	All-3	---	Protecting and improving access to tributaries will increase the quantity of available habitat, particularly for juvenile Chinook and coho salmon, and lead to expanded salmon spatial distribution, greater juvenile salmon growth, and higher survival.	• Remove culverts and flapgates that are perched or otherwise limit fish access, particularly access to rearing areas for juvenile Chinook and coho • Modify tributary mouth configuration to improve access over range of flow conditions • Restoring natural sediment recruitment and reducing channel downcutting	• All-7 • Low-4	• All lifestages	• Increase food availability • Expand areas providing refuge from predators • Provide high energy/flow refuge • Enhance migration corridor • Expand rearing habitat • Expand spawning ground availability	• Abundance • Diversity • Spatial Structure	• Salmon utilization of tributaries will increase with improved access and habitat condition • Increased utilization will lead to longer residence times, higher survival, and greater distribution	• Kerwin and Nelson (2000)	• Restore / Moderate

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
Applicable to entire WRIA	All-4	---	Allowing natural disturbance-type flows in a relatively unconstrained river channel will enhance habitat diversity and provide habitats that can support spawning and rearing salmon at a greater variety of flow conditions (compared with high flows in a constrained channel), thereby leading to expanded salmon spatial distribution, greater juvenile salmon growth, and higher survival.	• Implement a flow regime that more closely reflects the natural flow regime, including natural peak flows that create side channels and enhance mainstem habitat in unconstrained portions of the river • Concurrently, set back levees to allow river to meander within the broader channel zone and to reduce scour related impacts by allowing high flows to spill over banks to connected floodplain • If levees cannot be set back, then manage flow regime to prevent losing a significant portion of year class due to redd scour	• All-2 • All-3	• Egg incubation • Juvenile freshwater rearing • Adult holding • Adult spawning	• Improve egg-to-fry survival • Enhance rearing habitat • Expand spawning ground availability • Improve spawning ground quality • Enhance rearing habitat	• Abundance • Productivity • Diversity • Spatial Structure	• Natural disturbance creates more diverse and complex habitat for salmon • Habitat complexity enhances productivity and increases life history diversity • Scour impacts on redds are excessive and limit egg-to-fry survival	• Franklin (1992)	• Rehabilitate/ Low-Moderate • Preserve / High
	All-5	---	Preserving and protecting against watershed and upland impacts by implementing Low Impact Development techniques, including minimizing impervious surfaces, will maintain habitat quality by helping maintain flow, maintain water quality, and reduce sedimentation, thereby leading to greater salmon survival.	• Maximize forest retention and minimize impervious surfaces through improved site design • Use pervious materials, such as pervious concrete, for hard surfaces such as parking areas • Maintain/restore riparian area native vegetation • Maintain vegetation to the maximum extent practicable on all development sites • Purchase conservation easements • Implement stormwater management techniques that promote infiltration and reduce water quality impacts (especially temperature and turbidity)	• All-1 • All-2 • Low-3 • Mid-2 • Mid-5	• All lifestages	• Maintain food availability • Maintain physiological refuge • Maintain migration corridor • Maintain rearing habitat • Maintain adult homing and upriver migration survival	• Abundance • Productivity	• Degraded watershed conditions and functions reduce the quantity and quality of instream habitat • Reduced quantity and quality of instream habitat reduces productivity and diversity of salmon		• Restore / Moderate • Preserve / High

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	All-6	---	Preventing new bank/shoreline armoring and fill and removing existing armoring, fill and other impediments (e.g., levees) will enhance habitat quality and quantity and lead to improved juvenile salmon survival, spatial distribution, and diversity.	• Use best management practices (BMPs) (e.g., setbacks and buffers) when developing in aquatic areas, especially flood and landslide hazard areas • Remove bulkheads, levees, and other impoundments • Remove fill and allow natural inundation by fresh and tidal waters to create wetlands, marshes, and side channels • Reconstruct estuaries, wetlands, flats, and beaches to expand spatial area/shallow habitats for refuge, prey production, migration, and physiological transition • Restore sediment transport processes	• All-2 • Near-2 • Near-3 • Near-4 • Mid-3	• All lifestages	• Increase prey production • Increase refuge • Provide high energy/flow refuge • Enhance migration corridor • Expand rearing habitat	• Abundance • Productivity • Diversity • Spatial Structure	• Increased habitat area, complexity, and diversity would result in increased species abundance, productivity, and diversity	• Williams et al. (2001) • Williams and Thom (2001) • WDOE (1994) • Terich and Schwartz (1993)	• Preserve / High • Restore / Moderate
	All-7		Maintaining adequate flows during low flow periods will improve water quality and enhance rearing and spawning habitat quality and quantity, and upstream migration/holding conditions for returning adults, thereby leading to greater survival.	• Implement a flow regime that augments base flows during low flow periods • Preserve inflow of groundwater from the White River and other sources	• All-1 • All-2 • All-3 • Low-1 • Mid-1 • Mid-5	• Adult migration • Adult spawning • Juvenile rearing • Juvenile migration	• Enhance rearing habitat • Improve spawning ground quality • Expand spawning ground availability • Improve adult migration	• Abundance • Productivity	• Low flows reduce the quantity of habitat and limit the quality of habitat for spawning and rearing • Current baseflows inadequate for rearing juveniles, primarily coho and steelhead • Low flows result in higher temperatures • Low flow inhabits adult migration		• Preserve / High • Rehabilitate / Low-Moderate
Nearshore (including Elliott Bay)	Near-1		Protecting and improving sediment quality, particularly in Elliott Bay will enhance habitat quality and lead to greater juvenile salmon growth and higher survival.	• Remove or remediate contaminated sediments • Address nonpoint sources through stormwater management and riparian vegetation management • Repair/replace failing septic systems • Cleanup contaminated sediments to remove from biologically active zone	• All-1 • Duw-2	• Juvenile foraging/rearing • Juvenile migration	• Increase food availability • Enhance resistance to disease • Increased growth	• Abundance • Productivity	• Sediment quality reduces the production of prey items consumed by juvenile salmon. • Enhanced prey availability will enhance survival.	• Powell et al. (2002) • Arkoosh et al. (1999) • Stein et al. (1995)	• Preserve / High • Restore / Moderate • Rehabilitate/ Low-Moderate

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	Near-2	---	Protecting and increasing the availability of vegetated shallow nearshore and marsh habitats will enhance habitat quantity and quality and lead to greater juvenile salmon residence time, greater growth, and higher survival.	• Add material to dredged areas or remove fill to create shallow habitat with natural gradient and substrate sizes and replanting/reseeding with appropriate submerged aquatic vegetation • Replace or cap low quality fill material • Remove nearshore shoreline armor and overwater structures to allow access to upper intertidal zones and reduce impacts to shoreline energy • Protect and restore shallow nearshore corridor	• All-6	• Juvenile foraging/rearing • Juvenile migration • Juvenile predator avoidance	• Increase food availability • Improve predator refuge • Enhance migration corridor • Enhance rearing habitat	• Abundance • Productivity • Diversity	• Restoration of shallow water habitats will increase the production of prey items consumed by juvenile salmon. • Enhanced prey availability will enhance survival.	• Simenstad et al. (1982) • Brennan and Higgins (2004) • Phillips (1984) • Toft et al. (2004)	• Restore / Moderate
	Near-3	---	Protecting and restoring nearshore sediment transport processes by reconnecting sediment sources and removing shoreline armoring that impacts sediment transport will lead to greater prey production, greater juvenile salmon growth and higher survival.	• Reconnect beach feeding sources to intertidal zone and allow for bluff erosion. Also, protect/restore low bank shorelines • Remove shoreline armor and fill • Undertake beach nourishment where above actions cannot be taken	• All-6	• Adult/subadult foraging • Juvenile foraging/rearing	• Increase food availability • Enhance migration corridor • Enhance rearing habitat • Increase and enhance forage fish spawning habitat	• Abundance • Productivity	• Restoration of nearshore processes will increase the production of prey items consumed by juvenile salmon. • Enhanced prey availability will enhance survival.	• Shipman (2004) • Dethier and Schoch (2000)	• Preserve / High • Restore / Moderate
Nearshore (including Elliott Bay	Near-4	---	Protecting and expanding forage fish spawning areas by maintaining/ increasing high intertidal zone access and maintaining/ increasing availability of suitable substrate sizes will lead to greater juvenile salmon growth and higher survival.	• Protect existing shoreline sections with suitable substrate in the appropriate intertidal elevations for forage fish spawning • Remove shoreline armoring to expand availability of high intertidal areas and minimize scouring actions that remove suitably sized substrate from the armored shoreline reach • Restore native vegetation in riparian areas to provide overhanging vegetation to reduce possibility of egg desiccation, among other functions	• All-6 • Near-2 • Near-3	• Juvenile foraging/rearing • Adult foraging	• Increase food availability • Enhance rearing habitat	• Abundance • Productivity	• Expanded forage fish spawning areas will lead to greater prey availability for juvenile and adult salmon. • Enhanced availability of forage fish prey will enhance salmon survival	• Brennan and Higgins (2004) • Fresh et al. (1981) • Brodeur (1990)	• Preserve / High • Restore / Moderate

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	Near-5	---	Protecting and enhancing pocket estuaries (i.e., small non-natal smaller estuaries, lagoons, and spits) and salmon-bearing and non-salmon bearing tributary mouths by maintaining/ restoring tributary mouths will increase quantity of key habitat and lead to greater juvenile salmon growth and survival.	• Remove shoreline armoring around tributary mouths to widen small creek deltas • Remove armoring that channelizes the lower reaches of tributaries and along shorelines in order to expand the transition zone to salt water • Restore alongshore sediment processes • Protect/restore riparian vegetation along pocket estuaries	• All-3	• Adult foraging (cutthroat, and possibly others) • Prey production • Juvenile transition • Migration • Juvenile foraging/rearing	• Increase food availability • Maintain or expand physiological transition zone	• Abundance • Productivity • Diversity • Spatial Structure	• Increasing spatial diversity of available habitats will support greater life history diversity • Enhancing pocket estuaries will lead to increased growth and survival	• Beamer et al. (2003) • Hirschi et al. (2003)	• Preserve / High • Restore / Moderate
Duwamish Estuary (RM 0.0 11.0)	Duw-1	0 – 11	Expanding and enhancing the Duwamish estuary, particularly vegetated shallow subtidal and intertidal habitats and brackish marshes by restoring dredged, armored, and filled areas, will enhance habitat quantity and quality and lead to greater juvenile salmon residence time, greater growth, and higher survival.	• Expand estuarine habitats • Provide off-channel habitats for early estuarine rearing • Add appropriately-sized, clean sediment material to dredged areas to create shallow habitat with natural gradient and substrate sizes • Remove fill material where appropriate to maintain spatial and structural complexity • Remove shoreline armor and overwater structures • Re-establish marsh vegetation and mudflats • Restore riparian vegetation	• Near-2 • Duw-3	• Early estuarine rearing of subyearling and yearling outmigrants	• Increase food availability • Improve predator refuge • Enhance migration corridor • Enhance rearing habitat • Expand physiological transition zone	• Abundance • Productivity • Diversity • Spatial Structure	• Improved estuarine habitat will increase residence time, growth, and survival • Restoration of shallow water habitats will increase the production of prey items consumed by juvenile salmon. • Enhanced prey availability will enhance survival.	• Nelson et al. (2004) • Simenstad et al. (1982) • Ruggerone and Jeanes (2004)	• Restore / Moderate • Rehabilitate / Low-Moderate • Substitute / Low
	Duw-2	0 – 11	Protecting and improving sediment quality will enhance habitat quality and lead to greater juvenile salmon growth, disease resistance, and higher survival.	• Remove or remediate contaminated sediments • Address nonpoint sources through stormwater management and riparian vegetation management • Repair/replace failing septic systems • Cleanup contaminated sediments to remove from biologically active zone	• All-1 • Near-1	• Early estuarine rearing of subyearling and yearling outmigrants • Adult migration • Adult holding	• Increase food availability • Enhance resistance to disease	• Abundance • Productivity	• Sediment quality reduces that production of prey items consumed by juvenile salmon. • Enhanced prey availability will enhance survival.	• Powell et al. (2002) • Arkoosh et al. (1999) • Stein et al. (1995)	• Rehabilitate / Low-Moderate

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
Duwamish Estuary (RM 0 11)	Duw-3	5.5 – 7	Enlarging the Duwamish River estuarine transition zone habitat by expanding the shallow water and slow water areas will enhance habitat quantity and quality of this key Chinook salmon rearing area, leading to greater juvenile salmon residence time, greater growth, and higher survival.	• Remove fill and provide large off-channel habitats for early estuarine rearing • Add riparian and wetland vegetation buffers • Add material to dredged areas to create shallow habitat with natural gradient and substrate sizes	• Duw-1	• Brackish water rearing of fry and fingerling life stages	• Increase food availability • Expand physiological transition zone • Increase refuge • Expand rearing habitat	• Abundance • Productivity • Diversity	• Fish will expand habitat use to areas that are newly available • The limited extent of the salinity transition zone due to modifications of the Lower Duwamish River reduces salmon residence time and growth • Improved estuarine habitat will increase residence time, growth, and survival	• Nelson et al. (2004) • Congleton et al. (1981) • Weitkamp and Ruggerone (2000)	• Restore / Moderate • Rehabilitate / Low-Moderate • Substitute / Low
	Duw-4	7 – 11	Protecting, creating, and restoring habitat that provides refuge (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.	• Reconnect off-channel areas • Add LWD to provide a velocity break from high flow velocities	• All-3 • All-6 • Low-1	• Egg incubation • Freshwater rearing • Adult holding • Adult spawning	• Increase food availability • Improve predator refuge • Expand physiological refuge • Provide high flow refuge • Enhance migration corridor • Improve spawning ground quality	• Abundance • Productivity • Diversity • Spatial Structure	• Lack of refuge habitat in upper estuary causes salmon to migrate downstream prematurely	• Nelson et al. (2004) • Ruggerone and Jeanes (2004)	• Restore / Moderate

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
Lower Green River (RM 11 32)	Low-1	11 – 32	Protecting and creating/restoring habitat that provides refuge (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.	• Reconnect off-channel areas and tributaries • Add LWD to provide a low velocity habitats during high flow events Add riparian vegetation enhancement and buffers • Reduce steep riverbanks through levee setbacks • Protect cold water sources that can provide temperature refuge	• All-3 • All-4 • All-6 • Duw-4 • Mid-1	• Egg incubation • Freshwater rearing • Adult holding • Adult spawning	• Increase food availability • Improve refuge from predators • Expand physiological refuge • Provide high flow refuge • Enhance migration corridor • Improve spawning ground quality	• Abundance • Productivity • Diversity • Spatial Structure	• Loss of habitat that serves as refuge in the Lower Green River limits freshwater productivity, diversity and spatial structure • Lack of refuge habitat in upper estuary causes salmon to migrate downstream prematurely, particularly during high flow events	• Nelson et al. (2004) • Ruggerone and Jeanes (2004)	• Restore / Moderate • Rehabilitate / Low-Moderate
	Low-2	11 – 32	Restoring and enhancing sediment recruitment (particularly spawning gravels) by reconnecting sediment sources to the river will reduce channel downcutting, increase shallow habitats, improve access to tributaries, and improve spawning habitat, thereby leading to greater juvenile salmon residence time, greater growth, and higher survival.	• Set back levees to reconnect natural sediment sources • Set back levees to allow for side channel formation and LWD recruitment • Target sediment sources upriver • Add riparian vegetation enhancement and buffers	• All-3 • All-4 • Mid-3	• Freshwater rearing • Adult holding • Adult spawning	• Expand rearing habitat availability • Expand spawning ground availability • Improve spawning ground quality	• Abundance • Productivity • Diversity • Spatial Structure	• Reduced sediment recruitment limits the availability of suitable spawning habitat • Improved spawning habitat in the Lower Green River will increase spawning • Natural sediment recruitment will improve access to tributaries	• Kerwin and Nelson (2000) • Nelson et al. (2004)	• Restore / Moderate • Substitute / Low • Rehabilitate / Low-Moderate
	Low-3	11-32	Preserving and maintaining groundwater inflow from historical White River channel will contribute to maintaining river flows and good water quality, thereby leading to greater juvenile and adult salmon survival.	• Protect White River groundwater connection to Green River	• All-1	• Freshwater rearing • Adult holding	• Maintain rearing habitat • Enhance migration corridor	• Abundance • Productivity	• Water quality downstream of the White River is limiting productivity • White River groundwater continues to provide a significant inflow during low flow periods		• Preserve / High

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	Low-4	Black River	Modifying the Black River Pump Station to allow fish passage will increase habitat quantity and lead to greater juvenile salmon residence time and growth.	• Allow fish passage above the Black River Pump Station, particularly into Springbrook Creek	• All-3	• Freshwater rearing	• Expand rearing habitat	• Abundance • Productivity • Diversity • Spatial Structure	• Water quality and quantity is adequate to support juveniles		• Restore / Moderate
Middle Green River (RM 32 64.5)	Mid-1	32 – 64.5	Protecting and creating/restoring habitat that provides refuge (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.	• Reconnect off-channel areas • Improve riparian vegetation condition and buffers to provide a source of future LWD • Add LWD to provide a low velocity habitats during high flow events	• All-3 • All-6 • Duw-4 • Low 1	• Egg incubation • Freshwater rearing • Adult holding • Adult spawning	• Increase food availability • Improve predator refuge • Expand physiological refuge • Provide high energy/flow refuge • Enhance migration corridor • Improve spawning ground quality	• Abundance • Productivity • Diversity • Spatial Structure	• Lack of refuge habitat in upper estuary causes salmon to migrate downstream prematurely	• Nelson et al. (2004) • Ruggerone and Jeanes (2004)	• Restore / Moderate • Rehabilitate / Low-Moderate
	Mid-2	32 – 64.5	Protecting against watershed and upland impacts by implementing Low Impact Development techniques (see All-5) will be particularly beneficial in the sub-watersheds of tributaries that provide spawning (e.g., Newaukum and Soos Creeks) and/or rearing habitat (e.g., Jenkins and Covington Creeks) will increase habitat quality and quantity and promote utilization of non-mainstem habitats and prevent creating additional stressors that limit survival.	• Use pervious materials, such as pervious concrete, for hard surfaces such as parking areas • Maintain/restore native vegetation in riparian corridors and all development sites, particularly in rural areas • Buffers on all wetlands, streams, and shorelines • Implement stormwater management techniques that promote infiltration and reduce water quality impacts (especially temperature and turbidity).	• All-1 • All-2 • All-5 • Mid-4 • Mid-5	• All lifestages	• Maintain food availability • Maintain physiological refuge • Maintain migration corridor • Maintain rearing habitat • Improve adult homing and upriver migration survival	• Abundance • Productivity • Diversity • Spatial Structure	• Degraded watershed conditions and functions reduce the quantity and quality of instream habitat • Reduced quantity and quality of instream habitat reduces productivity and diversity of salmon		• Preserve / High

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	Mid-3	32 – 64.5	Protecting and restoring natural sediment recruitment (particularly spawning gravels) by reconnecting sediment sources to the river will help maintain spawning habitat.	• Riparian protection/enhancement • Set back levees to reconnect natural sediment sources to allow for side channel formation and LWD recruitment • Add spawning gravels	• All-5 • Low-2	• Freshwater rearing • Adult holding • Adult spawning	• Expand rearing habitat availability • Expand spawning ground availability • Improve spawning ground quality	• Abundance • Productivity	• Improved spawning habitat in the Lower Green River will increase spawning and increase egg-to-fry survival • Natural sediment recruitment will improve access to tributaries	• Perkins (1993)	• Restore / Moderate • Substitute / Low
	Mid-4	Newaukum Creek and Soos Creek	Preserving and restoring spawning and rearing habitat in lower Newaukum and Soos Creeks will increase habitat quality and quantity, thereby increasing productivity and spatial structure of Green River Chinook salmon.	• Riparian protection/enhancement • Maintain/restore riparian vegetation • Limit development-related impacts, including levees • Protect cold water sources	• All-2 • All-3 • Mid-2	• Freshwater rearing Adult holding Adult spawning	• Increase food availability • Improve predation refuge • Provide high energy/flow refuge • Improve spawning ground quality	• Abundance • Productivity • Diversity • Spatial Structure	• Improved habitat quality in tributaries will lead to increased fish use, extended rearing time in freshwater, and increased survival • Newaukum and Soos creeks can provide quality habitat for wild salmon	• Kerwin and Nelson (2000)	• Preserve / High • Restore / Moderate
Middle Green River (RM 32 64.5)	Mid-5	45 – 58	Maintaining regional groundwater recharge and base flows to the mainstem Green River through forest retention and Low Impact Development will maintain spawning and rearing habitat.	• Riparian protection/enhancement • Protect natural hydrology • Protect cold water springs • Protect upland forest and wetlands	• All-1 • All-4 • All-5 • All-7 • Low-3 • Mid-2 • Mid-4	• Freshwater rearing • Adult holding • Adult spawning	• Increase food availability • Maintain holding area quality	• Abundance • Productivity	• Groundwater provides an important source of cold water which contributes to keep river temperatures lower • Degraded watershed conditions and functions reduce the quantity and quality of instream habitat • Reduced quantity and quality of instream habitat reduces productivity and diversity of salmon	• Kerwin and Nelson (2000)	• Preserve / High • Restore / Moderate

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	Mid-6	61 – 64.5	Restoring Chinook salmon access between the Tacoma Diversion Dam (TDD) and Howard Hanson Dam (HHD) by providing passage upstream and downstream at the TDD for natural origin Chinook will increase habitat quantity and expand spatial structure.	• Construct fish ladder/collection facility to collect and/or selectively pass adult fish • Construct a downstream fish passage facility • Trap and haul around dam *Note: Tacoma Water is constructing an adult fish ladder, trap, sorting facility, and water-to-water transfer facility at the TDD to enable passage of adult fish into the Green River watershed upstream of HHD and a juvenile bypass facility around the TDD for migrants from the upper watershed. Currently there are no plans to provide adult salmon access between TDD and HHD due to concerns about the effects of decaying salmon carcasses on the municipal water supply.*	• Up-1	• All life stages	• Expand rearing habitat • Expand spawning habitat	• Abundance • Diversity • Spatial Structure	• Salmon will spawn in reach if allowed access		• Restore / Moderate • Substitute / Low

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
Upper Green River (RM 64.5 93)	Up-1	64.5 – 93	Establishing/restoring Chinook salmon access above HHD by providing passage upstream (trap and haul) beyond HHD and the reservoir for natural origin Chinook and downstream passage for the progeny as well as first generation hatchery fry will increase habitat quantity and expand salmon spatial structure. (Alternate Hypothesis: Augmenting restoration of salmon populations above HHD by re-introducing spring Chinook from a neighboring river system (possibly White River) will expand Chinook distribution, diversity, and enhance abundance in the river.) (Alternate Hypothesis: Restoring salmon above HHD without the use of hatchery outplants or returning hatchery adults will recover Chinook without bypassing important evolutionary processes (i.e., the selection of the fittest adults for spawning, and juveniles for incubation). *Note: Final decisions on which fish to pass upstream are dependent upon NOAA Fisheries, USFWS, and the co-managers (WDFW and Muckleshoot Indian Tribe)*	• Construct fish ladder/collection facility to collect and/or selectively pass adult fish • Construct a downstream fish passage facility • Trap and haul around dam	• Mid-6	• All life stages	• Expand rearing habitat • Expand spawning habitat	• Diversity • Spatial Structure	• Availability of expanded habitats will lead to expanded salmon distribution and life history diversity	• USACE (2000)	• Restore / Moderate • Substitute / Moderate

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	Up-2	64.5 – 93	Protecting and restoring/enhancing habitat along the upper Green River mainstem and major tributaries (e.g., North Fork, Smay Creek) by restoring the riparian corridor and logging roads will enhance habitat quality and lead to greater residence time and survival (after the establishment of populations above HHD]).	• Remove or repair failing logging roads • Restore native vegetation • Maintain wide riparian corridor • Add LWD • Tacoma Water continues to manage land holdings in upper watershed (approximately 10 percent of land) as a "natural" forest management zone which will keep those areas largely intact • Trap and haul around dam	• All-2 • Up-1	• Egg incubation • Juvenile rearing • Adult holding • Adult spawning	• Improve egg survival • Increase food availability • Enhance rearing habitat • Improve spawning ground quality	• Abundance • Productivity • Diversity • Spatial Structure	• Improved habitat in upper watershed will enhance fish survival and lead to extended residence times and increased survival • Runs are re-established in upper watershed	• USACE (2000)	• Preserve / High • Restore / Moderate • Substitute / Moderate
	Up-3	64.5 – 93	Establish bull trout population above HHD by providing passage upstream (trap and haul) beyond HHD and the reservoir for returning adults and downstream passage for the progeny as well as hatchery fry will increase habitat quantity and expand spatial structure. *Note: Final decisions on which fish to pass upstream are dependent upon NOAA Fisheries, USFWS, and the co-managers (WDFW and Muckleshoot Indian Tribe)*	• Construct fish ladder/collection facility to collect and/or selectively pass adult fish • Construct a downstream fish passage facility • Trap and haul around dam	•	• All life stages	• Expand rearing habitat • Expand spawning habitat	• Diversity • Spatial Structure	• Upper watershed provides habitat to support bull trout	• Watson and Toth (1994)	• Restore / Moderate • Substitute / Moderate
NON-HABITAT CONSERVATION HYPOTHESES											

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	Non-Habitat-1	---	Employing live capture techniques to harvest hatchery salmon (marked) and release natural salmon will reduce mortality of naturally-produced salmon while providing the opportunity to harvest a greater percentage of hatchery fish and thereby reducing straying of hatchery fish to the spawning grounds.	• Use non-lethal fishing gear to target hatchery fish • Increase harvest of hatchery fish	•	• Adult	• Increase adult survival • Reduce interbreeding	• Abundance • Productivity	• The ability to keep fish alive and distinguish between hatchery and natural salmon will allow more natural fish to be released • By limiting catch of natural salmon, higher percentage of hatchery population can be harvested • Interbreeding has led to decreased productivity, abundance, and diversity of natural Chinook	• PSIT and WDFW (2001)	• N/A
	Non-Habitat-2	---	Modifying hatchery practices (e.g., more natural rearing conditions, smaller releases, release timing and location, genetic management, etc.) and improving the attractiveness of hatcheries to returning hatchery adults will lead to reduced interactions between hatchery- and naturally-spawned Chinook salmon, and enhance production of naturally spawned Chinook.	• Retrofit hatcheries to allow for natural rearing conditions • Adjust release timing and release location to minimize overlap with natural population • Limit release numbers to carrying capacity • Use only natural origin adults as broodstock • Enhance imprinting on unique odors prior to release • Add weir on mainstem upstream of Soos Creek to prevent hatchery straying	•	• All life stages	• Reduced hatchery and wild fish interactions • Increase spawning by natural origin adults	• Abundance • Productivity	• Reducing difference between hatchery and natural salmon while also reducing spatial and temporal overlap will reduce negative interactions on wild fish survival	• HSRG (2003)	• N/A

	ID	Targeted River Miles (RM)	Draft Conservation Hypothesis	Example Actions	Related Conservation Hypotheses	Lifestages Targeted	Targeted Functions	VSP Parameters Addressed	Key Assumptions	Data/ References	Habitat Management Strategy Type / Relative Certainty1
	Non-Habit at -3	---	Reducing harvest of nonsalmonid commercially and recreationally important species (e.g., Dungeness crab, and forage fish) will lead to greater prey availability for juvenile and adult salmonids	• Work with WDFW to reduce harvest of forage fish	•	• Adult foraging Juvenile foraging	• Foraging	• Abundance • Productivity	• Forage fish are a primary component of Chinook diets as they get larger than 150mm. Reducing direct harvest of a prey item will increase its availability to Chinook and increase growth and survival	• Brennan and Higgins (2004) • Fresh et al. (1981) • Brodeur (1990)	• N/A

Note: 1) Strategy type and degree of certainty as defined in the "Integrated Recovery Planning for Listed Salmon: Technical Guidance for Watershed Groups in Puget Sound" by the Puget Sound Technical Recovery Team and Shared Strategy Staff Group (Draft February 3, 2003). Relative certainty was presented based on an increasing uncertainty of success in achieving VSP parameters in order of the strategy types from protect (least uncertainty), restore, rehabilitate, to substitute (most uncertainty).
Yellow highlight denotes references cited by Technical Committee without a full citation provided.

6.4. GUIDELINES FOR RESEARCH, MONITORING, AND EVALUATION

Some questions arose in the process of developing conservation hypotheses that were not readily answerable with existing data. Research topics, some of which are addressed in the WRIA 9 Research Framework (Ruggerone and Weitkamp 2004), could include:

- Upper Green River - adequacy of habitat upstream of Howard Hanson Dam, appropriate stocks or life history types, appropriate level of human intervention (should there be a "hands off" approach of allowing natural origin recruits access to the habitat above the dam, or should artificial propagation be used to "jump start" the recolonization), adequacy of juvenile fish passage facilities, presence of bull trout;
- Middle Green River - adequacy of spawning and rearing habitats and the hydrological processes that create and maintain them, redd scour and flow studies, including connection to off-channel habitats, continued stock assessment/screw trap work;
- Lower Green River - adequacy of rearing habitats, but with more emphasis on the role of and need for refuge, particularly from high flows, continued stock assessment for natural and hatchery fish, habitat use surveys linking fish to habitat at various flows;
- Duwamish - monitoring fish use, growth, and survival in the transition zone as a test of the potential value of a larger scale program to expand this habitat, and assess residence time of Chinook, habitat use studies; and
- Nearshore/Elliott Bay - how salmonids use marine nearshore habitats, and the degree to which availability of marine nearshore habitats limit production, sediment transport, sediment quality, and relationship to VSP, and forage fish production.

The draft Phase 2 report suggests some guidelines for monitoring and evaluation, but specific plans are yet to be developed, as part of the habitat planning process.

Monitoring and evaluation is recognized as a critical component of the WRIA 9 Habitat Plan (and is included in the Steering Committee-approved scope of work) to help implementers understand the effectiveness of habitat management actions and their effect on the Chinook population. In the dynamic arena of salmon recovery planning, scientists have agreed that many of our assumptions and working hypotheses may not be correct. Monitoring and evaluation is one way of addressing the uncertainties.

6.5. GUIDELINES FOR ADAPTIVE MANAGEMENT

Adaptive management is a way to move forward when technical knowledge is imperfect and there are uncertainties. Uncertainties are acknowledged and actions are viewed as experiments. An effective adaptive management program will require monitoring to systematically provide feedback on salmonid population status and population and life stage-specific responses to conservation actions. The draft Phase 2 report suggests that adaptive management is likely to require considerable time, funds, and commitment on the part of all involved. Other important elements of an adaptive management program would include experiments that yield data that can be statistically interpreted (requires monitoring), experiments that are conducted at an appropriate scale in time and space, and commitment of the affected parties to consider the results in future decision making. Monitoring and adaptive management programs will be developed as part of the habitat planning process.

6.6. NEXT STEPS

Making the transition from conservation hypotheses to habitat management strategies and site-specific actions is the critical next step in the WRIA 9 habitat planning process. The transition involves integration with the necessary future conditions for habitat and fish populations that appear in Section 7 of this report.

During the second functional linkages workshop, the WRIA 9 Technical Committee and other participants began the discussion on integration with necessary future conditions. The following questions were devised as a means to move forward.

1. *Which VSP parameter or parameters most threaten long-term sustainability/viability?*
2. *Which kinds of habitat actions most directly affect which VSP parameters? (Consider temporal and geographical scale)*
    - *Abundance: habitat quantity*
    - *Productivity: habitat quality*
    - *Diversity: habitat complexity and distribution*
    - *Spatial Structure: habitat distribution*
3. *Which conservation hypotheses include the action(s) most likely to affect the limiting VSP parameter(s)?*
4. *Which conservation hypotheses and actions are expected to have the greatest effect?*

The Technical Committee has worked to address the four integrating questions, and further discussion appears in Section 8 of this report.

When the science of the Strategic Assessment is completed, habitat management strategies will be developed, using TRT guidance. A policy synthesis will follow, integrating social and economic values. Priority actions that are consistent with the subwatershed strategies will be developed in the form of alternative management scenarios or suites of management actions. Following adoption of the Habitat Plan by the WRIA 9 Forum and ratification by jurisdictions, monitoring plans and an adaptive management program would be implemented.

SECTION 7 – NECESSARY FUTURE HABITAT AND SALMONID POPULATION CONDITIONS

7.1. INTRODUCTION

This section summarizes the necessary future conditions to support a viable salmonid population (VSP) in WRIA 9 with a focus on Chinook salmon (WRIA 9 and King County DNRP 2004). Using scientific guidance for population recovery developed by the Puget Sound Technical Recovery Team (TRT), NOAA Fisheries, and the Shared Strategy for Puget Sound, VSP goals and objectives were established for the Green River population. Subsequently, using ecosystem and habitat guidance from many sources, the VSP goals were translated into more explicit ecosystem and habitat goals that will be the basis for strategies and actions in the Green-Duwamish River and WRIA 9. Using information from historical and current habitat and population conditions, including data on salmonid utilization of habitats, the necessary future conditions will give us targets from which we can develop our management strategies and actions.

Considerable work has been done by the WRIA 9 Technical Committee to describe the population characteristics of Green River Chinook and the condition of their habitats. Reliable population information, however, is difficult to obtain, especially for spatial structure and diversity. The establishment of targets for these two parameters relies, therefore, on the best available information and on inferences from indirect measures that correlate with diversity and spatial structure such as habitat type and location, and differences in environmental regimes within the river. The other two VSP attributes—abundance and productivity—have been the focus of much more attention in salmon management. Nevertheless, there remains a high degree of uncertainty around estimates of both parameters and, depending on the assumptions used in the calculations, estimates of abundance and productivity can vary widely. For the purposes of this recovery work, the estimates of abundance and productivity are based on the work of the TRT and references can be found in the population identification and viability papers posted on the TRT website (http://www.nwfsc.noaa.gov/trt/trt_puget.htm).

7.2. BACKGROUND AND GUIDANCE

Guidance for the recovery of Pacific salmon populations was used to frame the discussion of habitat and population performance necessary for a consistent and coherent approach to recovery that, if applied conscientiously, should give us confidence in the appropriateness and outcome of our actions. Furthermore, goals and objectives that are derived from the guidance can be used to describe the general ecological and environmental conditions that are necessary to support salmon recovery.

We focused on principles and desired future conditions that guide habitat and population management for recovery, including the following guidance (National Research Council 1992, Stouder et al. 1996, Spence et al. 1996, McElhany et al. 2000, and NOAA Fisheries 1996). We evaluated the necessary parameters of a VSP as expressed in McElhany et al. (2000) and promulgated by the TRT (TRT 2003) as the central framework for organizing recovery and the ecosystem-based approach advocated by the NRC (1992), NOAA Fisheries (1996) and Spence et al. (1996). Of particular note is specific guidance from McElhany et al. (2000), "In order to conserve the adaptive diversity of salmonid populations, it is essential to (1) conserve the environment to which they are adapted, (2) allow natural processes of regeneration and disturbance to occur, and (3) limit or remove human-caused selection or straying that weakens the adaptive fit between a salmonid population and its environment or limits a population's ability to respond to natural selection."

Principles and guidance for viable salmonid populations and recovery of evolutionarily significant units is summarized in the *Necessary Future Conditions for WRIA 9* report (WRIA 9 and King County DNRP 2004). This includes guidance on abundance, productivity, spatial structure and diversity, including information on catastrophic risks and its importance for spatial structure. There is also a section summarizing guidance for ecosystems and habitat, including NRC (1992), NOAA Fisheries (1996) and Spence et al. (1996). These principles and guidance were used together with information on historical conditions and current information on population performance, spatial structure, and diversity as a basis for determining necessary future conditions.

7.3. BASIS FOR DETERMINING NECESSARY FUTURE CONDITIONS

The present Green River Chinook population occupies a watershed that is vastly different from the watershed of the population in 1850. The Duwamish River was the mouth of a watershed that drained over 407,730 ha (1,575 square miles), including the Cedar River, Lake Washington, Green River, and White River. A series of events and diversions led to a loss of approximately 70 percent of the watershed area from the historical Greater Duwamish Watershed (see Section 1.4.3). In terms of salmonid populations, three Chinook populations were lost: the North Lake Washington fall population, the Cedar River fall population, and the White River early-run population. The Green River early run population was apparently severely diminished and eventually extirpated after construction of the Tacoma Diversion Dam. The implications of these losses to the viability of the Green River population are unclear. Of particular significance may be the loss of the early returning Chinook population (spring run) in the Green River. Today, only the Green River fall population remains. As a consequence of these changes, necessary future conditions are not synonymous with properly functioning conditions.

7.3.1. Population Performance Findings

The abundance and productivity analyses carried out for the Green River population by the TRT and the WRIA 9 Technical Committee revealed several interesting and sometimes ambiguous outcomes. Nevertheless, six main points emerged from the analyses:

- The population of the Green River is greatly affected by hatchery origin fish; the number of hatchery origin fish spawning naturally varies considerably--from about 30% to over 70% in a given year.
- Estimates of historical population size are quite variable but independent methods put the historical maximum run size at approximately 37,700 based on estimates derived from cannery pack data (Myers et al. 1998, King County DNRP 2004)
- Current mean natural origin run-size estimates vary between 11,200 (TRT, 2002) and 14,700 (Weitcamp and Ruggerone, 2000).
- Natural-origin recruit (NOR) spawner estimates vary as well but the TRT places the corrected estimate of mean NOR spawners at 618 with a coefficient of variation (CV) of 112%. The geometric mean for NOR spawners is 322.
- Productivity estimates are also variable with a cohort replacement ratio as calculated by the TRT showing a recruit/spawner ratio of NORs that varies between .02 and 23 with a negative trend.
- The long-term trend in median growth rate for NORs in the Green (assuming hatchery fish have a reproductive success equivalent to wild fish) is only 0.698 although the long-term trend in abundance is 1.075. If hatchery fish are assumed to be successful at spawning, the long-term growth trend of the of the population is positive—1.023. The variance around these estimates is quite high and caution should be exercised when evaluating the trend alone.

7.3.2. Spatial Structure Findings

The spatial structure analyses carried out for Green River Chinook population by the WRIA 9 Technical Committee is presented in the *Historical and Current Salmonid Population Conditions for WRIA 9* (King County DNRP 2004) report. The following is a brief summary of adult spawning distribution, juvenile rearing distribution and catastrophic risk assessment (WRIA 9 and King County DNRP 2004).

7.3.2.1. Adult Spawning Distribution

The spatial distribution of Chinook salmon spawning in the Green River was altered as a result of construction of the Tacoma Diversion Dam. Mainstem spawning is limited to downstream of RM 61.1, compared to approximately RM 88 historically. The control of flow and flood events combined with flood control levees/revetments has resulted in the mainstem being narrower, reduced spawning substrate, and thus, spawning habitat patches are likely smaller. The diversion of the White River and Cedar River, and the dewatering of the Black River have fragmented the historical spatial structure. The diversion of the White River eliminated the replenishment of spawning gravels at its historical confluence, affecting spawning downstream of RM 31.3. The current spawning distribution is a continuum of spawning throughout the Green River from RM 25.4 to 60.8 with patches of very high density, as compared to the expected spatial arrangement of discrete patches separated by long stretches of no spawning (see Figure 3.1). Hatchery practices have altered spawning distribution of the Green River Chinook population by contributing hatchery origin recruits (HOR) to natural spawning areas, including high density spawning near Soos Creek and the Icy Creek rearing ponds.

7.3.2.2. Juvenile Rearing Distribution

The dams that have blocked upstream migration of adults also limit juvenile rearing distribution in the Upper Green subwatershed. Channelization and flood control levees/revetments have reduced the availability of shallow channel edge habitat in most areas of the mainstem downstream of the dam, particularly in the Lower Green and Duwamish subwatersheds. Significant habitat loss has occurred in the Middle Green River limiting available refuge and rearing habitat and reducing residence time and spatial structure. Off-channel habitat has been reduced by 70 percent, slow-moving channel edge habitat, recruitment of large woody debris (LWD), and creation of new habitats has been reduced, and floodplain forests have been reduced by 40 percent.

Significant habitat loss has occurred in the Lower Green River, Duwamish estuary, and marine nearshore (including Elliott Bay). This loss has limited available refuge and rearing habitat and reduced residence time and spatial structure. Floodplain forests and wetlands have been reduced by 87 and 40 percent, respectively, in the Lower Green. Slow-moving channel edge habitat and access to floodplain habitats (e.g., oxbows) have been reduced through the construction of levees. Tributaries have become degraded and access has been restricted that has reduced their availability for rearing, and reducing juvenile distribution. The transition zone (area where juveniles adjust to hyperosmotic conditions) has been pushed upstream of historical conditions and has been reduced in area, from approximately RM 5.0 to 6.5 [work is planned to better define the geographic extent of the transition zone]. Riverine-tidal, estuarine, and palustrine wetlands have been significantly reduced, and slow-moving channel edge habitat has been lost due to construction of levees and channelization. The Smith Cove tidal marsh, Occidental Square area lagoon-marsh, and West Point marsh in Elliott Bay have been largely filled. Shallow-habitats have been reduced and sediment processes have been altered due to filling and heavy armoring of shorelines. Riparian vegetation has been severely reduced and disconnected from the channel edge and/or shoreline in all three subwatersheds.

7.3.2.3. Catastrophic Risk Assessment for Green River Chinook

A total of fourteen types of catastrophic events (natural and/or anthropogenic) were identified when evaluating extinction risk to the Green River Chinook (see WRIA 9 and King County DNRP 2004, Table 2). Spatial and temporal characteristics for each catastrophe along with their effects on the population were examined. High probability catastrophes include chemical or oil spills, landslides, major floods, and disease outbreak. The current spatial distribution of spawning subjects the Chinook population to a high degree of risk since the majority of spawning (82 percent) is contained within the mainstem from RM 61.1 to 33.0. Dam failure, landslides, and chemical/oil spills all pose threats to the spawning and rearing population within this segment of river.

7.3.3. Diversity Analysis

The diversity analyses carried out for Green River Chinook population by the WRIA 9 Technical Committee is presented in the *Historical and Current Salmonid Population Conditions for WRIA 9* report (King County DNRP 2004). The discussion below outlines the most significant changes in diversity over time in the Green/Duwamish watershed.

7.3.3.1. Adult Life History Diversity

Spring Chinook salmon have been extirpated from the Green/Duwamish watershed and only the fall stock remains. A shift in return time has occurred that is largely attributed to hatchery practices. The mean peak return timing to the hatchery racks is October 4 compared to two-weeks later in the mid-1940s and historical estimates of natural return peak occurring in the third week of October.

7.3.3.2. Juvenile Life History Diversity

Five juvenile life history trajectories have been identified in WRIA 9. However, only two of those trajectories, *estuarine-reared fry* and *marine-direct fingerling*, are common today. A *yearling* life history trajectory continues to be present, but it is now rare; it is believed that this trajectory may have been common in the past since a spring stock was likely present. *Lower river-reared fry* and *marine-direct fry* appear to be uncommon today, although historically they may have been more abundant because of greater genetic diversity and habitat complexity. Significant loss of habitat in the estuary and lower river has likely negatively impacted habitat capacity, growth rate, residence time, and survival, especially among trajectories or life history types that rear in freshwater or the estuary for longer periods. These changes have likely reduced or eliminated behavioral variation by forcing juveniles to move through the river faster as they searched for adequate rearing habitat and food while avoiding predators.

7.3.3.3. Genetic Diversity

Major riverine diversions within the historical Greater Duwamish watershed have reduced the number of independent Chinook populations from five to one. Straying and gene flow among the five populations have been severely reduced due to human actions that have isolated the populations. A significant amount of genetic interchange between wild and hatchery-origin Chinook has occurred through constant intermingling on the spawning grounds during the past century.

7.4. NECESSARY FUTURE CONDITIONS

This subsection summarizes the necessary future VSP goals and rationale, and habitat conditions to support a viable population in WRIA 9 (WRIA 9 and King County DNRP 2004).

7.4.1. Abundance Goals and Rationale

In the absence of TRT goals for abundance for the Green River population, a precautionary approach was used based on the historical run size estimates noted in Section 7.3.1 to provide some provisional targets for the population. This historical range was coupled with the population viability calculations from the TRT (approximately 17,000 for most independent populations of Puget Sound Chinook) to establish a range for population viability. The lower bound can be set at 17,000 adults for equilibrium run size and the upper bound probably lies somewhere around 37,700, the historical abundance estimate. Since there is always considerable measurement and model error in these calculations, a reasonable target for the population might lie near the midpoint of these estimates at about 27,000 adults. When historical and current capacity estimates are made, and the results of the habitat modeling exercise by the Muckleshoot Indian Tribe (MIT) is finalized and released, a more confident estimate of target equilibrium run size can be made. The following is a brief summary of abundance goals:

- In the near term (over the next 10 to 15 years), a more critical target should be the number of NOR spawners in the system. In the Green River, the number of NORs is small and could become much smaller with increasing hatchery influence. From 1993 to 2002, the TRT calculated the mean number of NOR spawners to be 1,737; the geometric mean is 761. If we use the average NOR spawning population size (N) from TRT calculations (1,737), and a ratio of about 0.3 between the breeding population size (N_b) and the total population size (Bartley et al. 1992; Waples 1990, Waples et al. 1993), the average NOR breeding population is about 521/year. The population appears to be very near the "critical population threshold" and should be increased to the upper values suggested in the VSP guidelines—1,000 to 4,200/year.
- A concomitant effect of low population size is often the loss of distinct spawning aggregations (DSA) as population numbers fall. Given the low numbers of NORs, it is likely that many once-distinct aggregations have indeed been lost. The number of DSAs may have fallen by a factor of 10 or more based only on the historical population size. The current number should rise as the number of NORs is increased in the population and the DSAs should disperse throughout the available habitat (provided that habitat conditions are suitable for dispersal).

7.4.2. Productivity Goals and Rationale

To a large extent, the overwhelming presence of hatchery origin recruits (HORs) on the spawning ground may mask a decline in productivity of NORs. Calculations by the TRT for long and short-term productivity show considerable variation depending on the assumption used for HOR reproductive success. If HORs are assumed to be as effective as NORs, then both short- and long-term trends in median growth rate (λ) are considerably less than 1. If HORs are assumed to have less reproductive success on the spawning ground, then the short-term trend approaches 1 (although still less) while the long term trend is greater than 1. The actual value of HOR effectiveness probably lies between 0 and 1, and both short- and long-term trends would then be closer to and just below 1. Even if adjusted for HOR reproductive success, this short-term trend is disturbing and should be adjusted upward if possible. The importance of productivity is mirrored by the emphasis it received from the WRIA 9 Technical Committee, placing productivity at the top when ranking VSP parameters for effect on population viability in the Green River (see Section 8.1.2). The following is a brief summary of productivity goals:

- Given the estimated value of NOR breeders, the short term decline in productivity becomes problematic. If we use the target of 1,000 as an effective population size (N_b) for NORs, then the rate of growth to achieve this target in 15 years is approximately 1.05, slightly higher than the long-term median growth rate (where HOR effectiveness is 0). Given the error in estimating λ and the error in HOR effectiveness, a growth rate of 1.05 should be considered a minimum value.

- Consistent with the expansion of spawning aggregations for NORs, the number of suitable habitat patches for successful spawning should probably be higher as well. If the number of aggregations is to rise, the number of patches suitable for occupation should rise also. Examining the predictions of the viability model more closely, the case could be made that the number of suitable patches for NORs must at least quadruple to achieve the NOR abundance target. If replacement of HOR spawners with NOR spawners is factored in, an increase in the number of NOR occupied patches of at least 50% seems warranted.
- The reoccupation of patches and the reduction in the effect of HORs on NOR productivity can only be accomplished if the number of HORs on the spawning ground is reduced. Following the recommendations of the HSRG/WDFW/NWIFC Technical Discussion Paper #1 (2004), the goal is to reduce the HOR escapement to the spawning grounds to 5 percent or less of the NOR population in any given year.

7.4.3. Spatial Structure Goals and Rationale

Spatial structure is important for at least three reasons: (1) the distribution of sub-population units throughout suitable habitats (spawning and rearing distribution) reduces the risk posed by catastrophic events; (2) the wide distribution allows normal rates of demographic processes—immigration, emigration, gene flow—to occur between population sub-units; and (3) spatial structure within a population can lead to increased diversity of life history trajectories. In the historical Duwamish, among population spatial structure was represented by five populations scattered within three large subwatersheds (see Section 2.4.1). The spatial structure of the remaining Green River population has been affected by a variety of changes in the river ecosystem. The result has been a contraction of the population's range within the watershed, increasing its susceptibility to catastrophic risk, and reducing the number of life history trajectories that are spatially based. The following is a brief summary of spatial structure goals:

- A significant contribution to population viability can be achieved by recovering spatial structure of spawning and rearing salmon above the dams. Five main areas of spawning structure above the dams are suggested by the Core Areas work (Martin et al. 2004) and should be targeted for re-occupation by both spawning and rearing Chinook.
- Recovery of spatial structure below the dams is warranted also. A useful target for occupancy in this portion of the river would be that 65% of historical habitat patches would be suitable for occupancy at any given time (Half of those patches or 33% of the historical total would be source patches for the population) (see Section 7.4.5). This would bring occupied patches into closer proximity and allow interactions among more numerous local aggregations. These patch recovery goals should focus on providing suitable rearing habitat for juveniles.
- Soos and Newaukum Creeks are now occupied by Chinook and have become established spawning aggregations. Since occupied patches were lost in the mainstem river, these tributaries, perhaps augmented by hatchery practice and inadvertent habitat change, have become new elements in the spatial structure of the population. These areas should be protected as aggregations that reduce the risk from catastrophes affecting the mainstem river.
- Refugia are areas within a watershed that provide persistent habitat conditions that support the population during environmental perturbations. In the Green River, capturing multiple aggregations of the spawning and rearing population into refugia in the upper and middle mainstem river, the estuary and the nearshore would assist in the maintenance of spatial structure within the population.

7.4.4. Diversity Goals and Rationale

Diversity, a result of local adaptation, is often considered to be the hallmark of salmon populations. Diversity encompasses population and sub-population differentiation: variation within a population

related to size, fecundity, age structure, life history types and trajectories, and genetic variation. Diversity in the Green River has been reduced in at least two ways (exclusive of the larger loss of diversity associated with the diversions and loss of three populations). By most accounts, an early run of Chinook once occupied the Green River upstream of the Green River Gorge and the dams, but it is now considered to be extinct by the TRT. Second, the expression of life history types and trajectories has been reduced as habitats throughout the river (including the estuary and nearshore) have been modified and lost. The following is a brief summary of diversity goals:

- Since the existing life history types are the basic material for future adaptation of the species, the existing life history trajectories must be conserved.
- The opportunity for the expression of historical life history trajectories should be enhanced. This would require the recovery of historical habitat types and some proportion of their quantity in several areas of the river: Upper, Middle, and Lower Green, Duwamish estuary and marine nearshore.
- Increase variability in age structure for the population. This includes an increase in the proportion of 5- and 6-year old spawners, but could also include an increase in yearling outmigrants. This serves to spread the population over time and reduce the risk of population failure during any given year.
- The recovery of an early run life history type in the Upper Green would serve to expand both life history types and trajectories in the Green River. This would certainly provide significant conservation value to the ESU and the south Sound geographic area.
- Expand the run and spawn timing for the existing fall Chinook population to more appropriately mirror the historical timing.
- Other components of diversity have not been so well studied as age structure and life history trajectories. These other components (e.g., size, fecundity, age at migration) should be studied for negative trends over time as part of an adaptive management program.

7.4.5. Further Rationale for Necessary Future Conditions

The translation of VSP parameters into actual population attributes, and then into ecosystem and habitat characteristics, is not so straightforward as might first be imagined. The complex interaction among the four VSP parameters makes any independent analyses and evaluation of a single parameter of limited use when attempting to achieve viability for the population across its environment. Since the WRIA 9 Technical Committee did not employ a quantitative model at this stage of the analysis (no EDT analyses were available and the MIT was developing the SHIRAZ model), no specific, quantitative estimates of habitat volume necessary to support the population are made. Rather, the estimates for Necessary Future Conditions are based on a theoretical landscape approach to habitat dynamics and distribution (Wiens 2002) as informed by the historical conditions of the Green River, and recent work on core areas (Martin et al. 2004) and habitat disturbance (Frissell et al. 1986; Benda 1994; Bisson et al. 1997) and suitability (G. Reeves, personal communication).

An examination of the work by Martin et al. (2004) and some recent work by Bilby et al. (1999) reveals interesting information on the distribution of productivity within segments of a river system occupied by a population. Although separated by considerable distance, it is suggested that the main sources of productivity of a population, as far as spawners are concerned, tends to be concentrated in relatively discrete portions of the watershed, often amounting to about one-third of the available spawning habitat within the population range. This comports reasonably well with independent observations from the Oregon Coast Range (Reeves et al. in preparation) that suggest that at any given time about a third of a watershed, and by extension, about a third of river habitat is of sufficiently high quality to support the source areas of a population. Another third is of moderate quality and may exhibit sporadic spawning, and a further third is of low quality and does not support spawning at all. These are only rough estimates

but suggest habitat turnover rates of about 35 % in one hundred years in response to disturbance regimes within the watersheds evaluated.

There is little information on patch turnover rates and habitat suitability variation in Puget Lowland river systems and the application of coastal Oregon information must be viewed with caution. Even with these caveats, it might suggest that on average over a 100-year time frame about one-third of the habitat patches will be in some state of disturbance, recovery, or recovered at a given time. Thus, at any given time, one third of the patches within a river segment will be of high quality (this is the PFC standard of NOAA) while two-thirds will be recovering from the disturbance. Of this two-thirds, it is reasonable to expect that some portion will have been only recently disturbed and unsuitable as habitat while another third will be of sufficient quality to provide at least some measure of productivity (this may be the "at risk" portion of properly functional conditions). It seems prudent that a target for habitat suitability and viability should reflect this distribution of habitat suitability. Thus, of all the historical patches or core areas within a river, one might expect that a third will be occupied and productive at any time while a third will be mainly unoccupied due to habitat unsuitability. The remaining third will provide some habitat value for the population as secondary habitats. Thus, we would expect that at least two-thirds of the potential habitat patches in a river segment will be available, suitable to moderately suitable, and at least partially occupied at viability. Applying this information to the Green-Duwamish Watershed, the necessary future targets for suitable salmonid habitat will be 65 percent of historical habitat at any given time except in those subwatersheds where major river diversion have occurred (see Section 7.4.6 below).

7.4.6. Necessary Future Habitat Conditions

The information from the historical and current habitat and population (VSP) conditions, the change analysis, salmon ecology in WRIA 9, and functional linkages between habitat and salmonid populations (Sections 2, 3, 4, 5, and 6), together with the watershed-wide necessary future VSP goals from the previous subsections of Section 7, was used to identify necessary future habitat conditions by subwatershed (WRIA 9 and King County DNRP 2004). For each subwatershed, existing conditions supporting a potentially viable Chinook population were summarized and the key habitats and habitat features were listed. VSP parameter goals were identified for each subwatershed using the watershed-wide VSP goals given in Sections 7.4.1 through 7.4.4 as a basis. For each subwatershed, the assessment segments identified in Section 4 were used as the unit for specifying necessary future habitat conditions. In some instances, assessment segments were grouped together if the identified future habitat conditions were similar. In other cases, assessment segments had reaches with different necessary future habitat conditions. For each assessment segment, there is a brief description of habitat and population conditions and habitat constraints. See the *Necessary Future Habitat Conditions in WRIA 9* report (WRIA 9 and King County DNRP 2004) for more detail on the subwatershed and segment VSP goals and habitat characteristics and constraints.

Due to the watershed changes that have resulted from the diversion of the Cedar and White rivers, and the dewatering of the Black River, necessary future habitat area targets in the subwatersheds that are downstream of these hydrologic changes have been adjusted to more closely reflect current conditions. Loss of historical watershed area, and by rough extension the loss of flow, was used to determine target percentages. Above the historical confluence of the White and Green rivers, approximately 55% of the contributing area was in the White River drainage area; therefore in our analysis assessing future habitat conditions, we target 45% of the historical habitat for the Lower Green River as the reference condition. Similarly, at the historical confluence of the Black and present-day Green rivers, approximately 70% of the contributing area was in the Black and White drainage areas. Thus, in our analysis assessing future habitat conditions, we target 30% of the historical habitat for the Duwamish River as the reference condition.

7.4.6.1. Upper Green River Subwatershed

The Upper Green River subwatershed extends from approximately RM 65.4 at Howard Hanson Dam to the headwaters of the Green River at approximately RM 94.1. Mainstem channel morphology is variable; alternating between large confined channel types and unconfined floodplain channel types. Major tributaries include the North Fork Green River, Smay Creek, Charley Creek, Champion Creek, Sawmill Creek, Tacoma Creek, Twin Camp Creek, and Sunday Creek. There are five assessment segments within the Upper Green subwatershed. They are *Reservoir Plus* (Segment 8, RM 64.5 – 72.7), *Smay Valley* (Segment 9, RM 72.7–77.0), *Mile Canyon* (Segment 10, RM 77.0 –77.9), *Lester* (Segment 11, RM 77.9–84.1) and *Intake Valley* (Segment 12, RM 84.1–88.3). The necessary future habitat conditions identified for the Upper Green subwatershed follow:

- Core areas predicted as likely providing source population structure are targeted as refugia for both adult and juvenile Chinook. (Segments 9, 11, and 12)
- Natural rates of lateral channel migration are reestablished to create and maintain functioning aquatic habitats that represent ~65 percent of historical levels at any give time. (Segments 8, 9, 11, and 12).
- Hydrologic connection to floodplain and side channel habitats are restored to achieve access to ~65 percent of historical habitat areas at any given time. (Segments 9, 10, 11 and, 12)
- Natural rates of sediment recruitment are reestablished to increase productivity of spawning areas and to maintain and develop habitat. LWD quantity and distribution are increased after the channel begins to return to equilibrium conditions. (Segments 8, 9, 11, and 12)
- Water quality meets State standards to increase productivity of spawning areas (e.g., increase egg-to-fry and spawner-to-spawner productivity) and to increase juvenile life-stage productivity. Stream temperatures comply with water quality standards for rearing and migration for Sunday Creek. (Segments 8, 9, 11, and 12)
- Mainstem, off-channel and tributary habitats are improved to increase juvenile rearing, life-stage diversity and productivity (increase egg-to-fry and fry-to-fingerling survival rates). Habitats include braided channels, side channels, shallow channel edges, LWD jams, and in-channel pools. Targets are functioning habitats representing ~65 percent of historical habitat area at any give time. (Segments 8, 9, 11, and 12)
- Riparian zone is functioning and effective buffer widths are established to provide all riparian functions (shade, bank stabilization, sediment control, organic litter, large woody debris, nutrients, and microclimate). (Segments 8, 9, 10, 11, and 12)

7.4.6.2. Middle Green River Subwatershed

The Middle Green River Subwatershed starts at approximately RM 32 just below the confluence of Soos Creek and continues to Howard Hanson Dam at approximately RM 64.5. Mainstem channel morphology is variable; alternating between large confined channel types and unconfined floodplain channel types. Major tributaries include Soos Creek and Newaukum Creek. Smaller tributaries include Burns Creek, Crisp Creek (also known as Keta Creek), O'Grady Creek, and nine other locally named or unnamed tributaries. There are four assessment segments within this subwatershed. They are *Middle Green Valley* (Segment 4, RM 31.3–45.3), *Green River Gorge* (Segment 5, RM 45.1–57.6), *Boulder Zone* (Segment 6, RM 57.6–60.5), and *Eagle Gorge* (Segment 7, RM 60.5 – 64.4). The necessary future habitat conditions identified for the Middle Green subwatershed follow:

- Refuga are established that provides habitat to support both juvenile and adult Chinook. (Segment 4)

- Water quality and quantity meet State and instream flow standards to increase productivity of spawning areas (e.g., increase egg-to-fry and spawner-to-spawner productivity) and to increase juvenile life-stage productivity. (Segments 4, 5, 6, and 7)
- Sediment recruitment and transport rates approach natural rates to increase productivity of spawning areas and to maintain and develop habitat (e.g. pool tail outs, spawning riffles, shallow channel edge) for improving life history productivity. Sediment target with suitable gravel size is 6,300 CY/year to support spawning habitat. (Segments 4, 5, 6, and 7)
- Natural rates of lateral channel migration are reestablished to create and maintain functioning aquatic habitats that represent ~65 percent of historical levels at any given time. (Segments 4 and 6)
- Natural disturbance events are less restrained to support the creation of new habitats, and to recruit sediment and large woody debris. (Segments 4 and 6)
- Mainstem, off-channel, and tributary habitats are improved to increase juvenile rearing, life-stage diversity and productivity (increase egg-to-fry and fry-to-fingerling survival rates). Targets are functioning habitats representing ~65 percent of historical habitat area at any given time. Habitats include braided channels, side channels (target = 16 km in Segment 4), shallow channel edges, LWD jams (target = 50 pieces/km), and in-channel pools (target = 6 channel widths/pool). (Segments 4 and 6)
- Hydrologic connection to floodplain and side channel habitats are restored to achieve access to ~65 percent of historical habitat areas at any given time. (Segments 4 and 6)
- Riparian zone is functioning and effective buffer widths are established to provide all riparian functions (shade, bank stabilization, sediment control, organic litter, large woody debris, nutrients, and microclimate). (Segments 4, 5, 6 and 7)
- Sub-populations of natural origin recruits (NOR) in Newaukum Creek and Soos Creek are maintained to protect against catastrophic risk and the maintenance of spatial structure within the population. (Segment 4)
- Sources of cool, clean water from surface and ground water are maintained. (Segment 5)
- Provide access to additional spawning areas between RM 61.1 and 64.4 to increase productivity and abundance by expanding spatial structure. (Segment 7)

7.4.6.3. Lower Green River Subwatershed

The Lower Green River Subwatershed starts at approximately RM 11 (Black River confluence) and continues to approximately river mile 32 (below Soos Creek confluence). There is one assessment segment within this subwatershed: *Lower Green Valley* (Segment 3, RM 11.0 - 31.3). The necessary future habitat conditions identified for the Lower Green subwatershed follow:

- Water quality and quantity meets State and instream flow standards to increase productivity of spawning areas (e.g., increase egg-to-fry and spawner-to-spawner productivity) and to increase juvenile life-stage productivity.
- Sediment processes and transport rates that produce spawning gravel (RM 25 to 32) are reestablished and improved to increase productivity spawning areas, increase spatial structure, and maintain and develop habitats (e.g. pool tail outs, spawning riffles, shallow channel edge) that will increase life history productivity. Spawning habitat target with suitable gravel size is ~45 percent of historical levels (XXXX CY/year) for viability of population.
- Mainstem, tributary, and off-channel habitats are improved to increase juvenile rearing, life-stage diversity and productivity (increase egg-to-fry and fry-to-fingerling survival rates. Targets are functioning habitats representing ~45 percent of historical habitat area. Habitats include side

channels (target = 4.5 km), wetlands (target = 763 ha), tributaries within the valley bottom (target = 36 km), ponds (target = 13 ha), shallow channel edges, LWD jams, and in-channel pools.

- Hydrologic connection to floodplain, tributaries and historical off-channel habitats are restored to achieve access to ~45 percent of historical habitat area.
- Riparian zone is functioning and effective buffer widths are established to provide all riparian functions (shade, bank stabilization, sediment control, organic litter, large woody debris, nutrients, and microclimate).

7.4.6.4. Duwamish Estuary Subwatershed

The Duwamish Subwatershed extends from the mouth of the Duwamish River in Elliott Bay to RM 11 (Black River confluence). This section of the Green/Duwamish River is a brackish estuarine environment with tidal influence. The Duwamish Subwatershed contains two assessment segments *Tidal Delta* (Segment 1, RM 0.0–1.5) and *Duwamish Valley* (Segment 2, RM 1.5–11.0). However, they are being treated as one for the necessary future conditions since their goals and targets are similar. The necessary future habitat conditions identified for the Duwamish Estuary subwatershed follow:

- Water quality meets State standards to prevent recontamination of sediments and provide cool, clean water required for healthy salmonid habitat, including juvenile and adult migration.
- Sediment recruitment and transport rates approach natural rates to improved and maintain existing habitat and support habitat development (estuarine and riverine mudflats and marshes) that will increase life-stage productivity.
- Sediment quality meets State sediment management standards and achieves conditions consistent with the State/Federal cleanup process to improve life stage productivity.
- Impediments (e.g. overwater structures) to Chinook and salmonid migration are reduced.
- Mainstem, off-channel, and tributary habitats are improved to increase juvenile rearing, life-stage diversity and productivity (increase egg-to-fry and fry-to-fingerling survival rates). Targets are functioning habitats representing ~30 percent of historical habitat area. Habitats include shallow channel edge, Palustrine and Riverine-tidal wetlands (target = 108 ha), and off-channel habitat (target = 2 ha).
- Estuarine habitat (transition zone area, where juveniles adjust to hyperosmotic conditions) is expanded to encompass ~30 percent of historical habitat area (target is ~70 ha) and habitat quality is functioning to improve juvenile growth and survival rate.
- Riparian zone is functioning and effective buffer widths are established to provide all riparian functions (shade, bank stabilization, sediment control, organic litter, large woody debris, nutrients, and microclimate).

7.4.6.5. Marine Nearshore Subwatershed

The Marine Nearshore subwatershed lies within the central Puget Sound basin and includes marine shorelines of Vashon and Maury Islands and Elliott Bay south to the Pierce County line on the mainland, comprising approximately 90.6 lineal shoreline miles. There are nine assessment segments in this subwatershed, five assessment segments on the mainland, and four assessment segments on the islands. The necessary future habitat conditions identified for the Marine Nearshore subwatershed follow:

- Water quality of tributaries meets State standards to increase productivity of pocket estuaries and marine nearshore areas to increase juvenile and adult life stage productivity;
- Marine sediment recruitment and transport rates approach natural rates to maintain existing habitat and support habitat development to increase life-stage productivity

- Sources of cool, clean water from groundwater supporting marine nearshore springs and seeps are maintained.
- Impediments (e.g. overwater structures) to Chinook and salmonid migration are reduced.
- Marine nearshore habitats are improved to increase juvenile rearing, life-stage diversity, and productivity. Marine nearshore habitats include salt marshes, beaches and backshore, pocket estuaries, and shallow water habitat
- Marine riparian zone is functioning and effective buffer widths are established to provide all riparian functions.

7.5. UNCERTAINTY IN THE ESTIMATION OF NECESSARY FUTURE CONDITIONS FOR CHINOOK RECOVERY

7.5.1. Sources of Uncertainty in the Data and Analyses.

Despite extensive historical and current analyses to estimate the VSP parameters of the Green River Chinook population, considerable uncertainty remains when attempting to derive the attributes of the population necessary for viability into the future. This uncertainty arises from four major sources: (1) the generally poor information about the historical (pre-contact) status of the population (its VSP attributes); (2) the limitations of historical habitat reconstruction; (3) the uncertainty surrounding the relationship between the population's VSP parameters and habitat; and (4) the lack of clear VSP objectives that equate to viability. In addition, more uncertainty arises from our inability to accurately predict the future; however, this type of uncertainty will not be covered.

7.5.1.1. Population Status (VSP Parameters)

Of the four VSP parameters necessary to judge viability, useful data exists only for abundance. Although even this information is scarce before about 1965 and reconstructing the historical population is virtually impossible. Current abundance data is problematic insofar as estimates of recruits—both NORs and HORs—are prone to error and constantly subject to revision. For example, recent mark-recapture data suggests that the most common method for estimating spawners on the spawning grounds underestimates the numbers by more than half.

The information regarding productivity, diversity and spatial structure is even more problematic. Estimates of productivity are confounded in the Green River by the influence of hatchery fish in the naturally-spawning population and the inability to separate hatchery origin spawners from natural origin spawners. Only the PSTRT attempted to separate these groups but these estimates are model-based and not actual empirical data. Historical spatial structure and diversity data are almost non-existent for this population except as anecdotes about fishing locations or supposed distributions from the early part of the 20th century that are assumed to represent historical distributions. At best, historical hatchery records provide some small clues. Additional information on the limitations and uncertainty associated with data for the four VSP parameters for the Green River Chinook population can be found in the Necessary Future Conditions in WRIA 9 report (WRIA 9 and King County DNRP 2004).

7.5.1.2. Habitat Analysis for Historical Conditions

This work has considerably less uncertainty than the VSP analysis since the work relies on actual historical documents for its evaluation. Still, few actual historical surveys of habitat exist in the Green River and habitat structure was inferred from topographic maps, survey books, and a variety of other sources (Collins and Sheik 2004). Combined with other analyses from the Forest Service and other

agencies, the work carried out in the Green-Duwamish River provides a useful template for assessing change. Uncertainty in this case arises mainly from analytical assumptions and methods, and from the resolution of the maps and accuracy of survey data. Moreover, the data tends to be synoptic and no analysis of trends was completed. Thus, the maps of the historical condition may under-represents a "normal" or average condition of the river at the scale of the reach or segment and quantifies only gross units of habitat: pools or gravel bars and riffles. These estimates will be useful for making estimates of carrying capacity and have been used to examine life history trajectories. More specific conditions of habitat quality cannot be answered with the map data and no good estimates of historical rates of landslides or change exist.

7.5.1.3. Relationships Between Populations and Habitat

Not that they are panaceas for evaluation, but quantitative population habitat models were not used in the historical or current analysis in WRIA 9. In an effort to address the uncertainty in the existing data, and with the absence of any data in some cases, WRIA 9 chose an ecological synthesis approach (see Section 6.2) that uses the principles and guidelines expressed in the NOAA Fisheries VSP work (McElhany et al. 2000), the NOAA West Coast conservation guidance (1996), and the guidance from the PSTRT (2003). The information obtained in the analytical work was evaluated in light of the four VSP parameters and the habitat guidance from NOAA Fisheries. The PSTRT guidance formed the basis for the setting of hypotheses of cause and recovery.

Even if copious data had been available about the Green River population, it would still be necessary to evaluate that information in light of the framework set out in the VSP work. Even lacking good, complete data, if the principles of the VSP and other work are valid, then a series of if-then statements (hypotheses) can be crafted that are testable as data is assembled in an adaptive management mode. This was not an excuse to omit or overlook data in the analysis, but rather a strategy to bound the interpretation of the existing data by asking for a suitable interpretation given the VSP guidelines. This is best seen in the analysis of productivity and the attention to NOR numbers. Despite the uncertainty surrounding the low estimates for NORs, the VSP guidance suggests critical population thresholds that must be met in any population. The NFC for productivity in the short run then becomes targeted to moving the population quickly to a productivity and abundance value that avoids the depensatory effects associated with a very low population.

7.5.1.4. VSP Objectives and Viability

Necessary to coping with uncertainty in any recovery work is to be clear about the assumptions that underlie the analysis and interpretation. This has been accomplished by both clarifying the assumptions in the analyses and by comparing them against the VSP and PSTRT assumptions for viability. In this way, the uncertainty of data and method can be carried through into the interpretation and evaluation, into the hypotheses, and finally into the management actions. Although no attempt to quantify the uncertainty inherent in the analyses has been made, a check of the assumptions in the analyses can provide a crude estimate of confidence in interpretation and evaluation. Further work must be done on this relationship between assumptions and uncertainty before confident alternatives and actions can be developed.

7.5.1.5. Using the Historical Template

Another way to cope with uncertainty in NFC is to employ the historical condition template where it is available, using it as a comparison to the proposed condition. The Properly Functional Condition (PFC) used by NOAA Fisheries is a kind of historical template, but is so general that it adds to uncertainty except as a comparative base. In the Green River, the use of any historical template is complicated by the considerable changes in the watershed over the last 100 or so years. Only about 30% of the original Duwamish watershed remains connected to the lower river; the Cedar and White rivers were long ago

diverted from the Duwamish. Thus, the effects of splitting off several populations and sources of flow complicate the use of the historical template as a guide. Nevertheless, for much of the Green River, the historical analysis was very informative. The principle applied to the Duwamish estuary and Lower Green was to use both the historical template and the concept of proportionality, where the loss of contributing area and flow was used to reduce the habitat volume by a like amount (see Section 7.4.6).

7.5.2. Uncertainty and Necessary Future Conditions

Overall, the analysis, interpretation, and proposed necessary future conditions rest on surrogates for viability and VSP parameters that cannot be measured directly. Given so little data about specific VSP parameters, the development of the necessary future conditions for those parameters and the habitat conditions necessary to support them can only rely on indicators of viability. For example, the spatial distribution of certain habitat types and the differences in adaptive regimes from the upper river to the lower substitute for direct observations of meta-population structure and diversity. The core-areas evaluation provides a prediction of both the historical population distribution and the potential future distribution. While highly theoretical, it has a basic logic that suggests validity for meta-population structure and viability. A closer look at the distribution of the proposed core areas suggests a pattern of life history trajectories and possible variations in diversity at the population level in the Green River. This work forms a hypothesis that will be tested during the recovery of the population(s).

When using the surrogates for VSP parameters, the guidance from NOAA was critical in interpretation and in formulating goals for the population. Where these goals could be derived directly from the guidance, they were applied to the Green River population. Always the target was viability for the population, even in the short term (see the immediate productivity goal, for example). The attempt here, in the face of such large uncertainty, was to be precautionary and err on the side of conservation. Even so, it is not possible to assign a quantitative level of risk to the population even if all the goals were fulfilled. Since no quantitative model was employed, a confident estimate of the relationship among the population goals and the habitat goals cannot be made. Such a model will necessarily have to be used sometime in the near future to assist in judging the outcome of the many management actions proposed to recover this population. At this time, however, the logic of the VSP framework applied to the analysis provides the main basis for confidence in formulating management actions.

SECTION 8 – SUMMARY, SCIENTIFIC FOUNDATION, AND NEXT STEPS

8.1. SUMMARY AND SCIENTIFIC FOUNDATION

This WRIA 9 Strategic Assessment (SA) summary report and the many individual SA reports and products represent the best available technical information (i.e., the science foundation) that will be used to support the development of habitat management strategies and actions in the WRIA 9 Habitat Plan.

This Strategic Assessment report summarizes information regarding historical and current habitat conditions, salmonid population conditions, water quantity and quality. Specific information is included on fish utilization, including juvenile migration and rearing patterns, habitat usage, and habitat limiting factors. All of this information is used to examine the functional linkages between habitat conditions and population response and to identify conservation hypotheses about the types of actions that will benefit fish populations. Finally, the report provides recommendations regarding necessary future conditions to support a viable population of Chinook salmon, as well as necessary future habitat conditions by subwatershed. The functional linkages work (Section 6) and necessary future conditions (Section 7) essentially synthesize the other Strategic Assessment products.

In this final section, the conservation hypotheses and necessary future conditions are linked based on the answers to key questions developed by the WRIA 9 Technical Committee and the SA consulting team. The objective is to integrate the conservation hypotheses and the necessary future conditions in a logical and transparent way and to establish priorities. The next step in the planning process is the development of habitat management strategies, WRIA-wide and for each subwatershed that will guide the actions that will be part of the WRIA 9 Habitat Plan.

8.1.1. Linking Conservation Hypotheses and Necessary Future Conditions

The Draft WRIA 9 Conservation Hypotheses, Functional Linkages Phase 2 Report (Anchor Environmental and Natural Resources Consultants 2004) identified a suite of 29 conservation hypotheses that focus on improving habitat conditions and habitat-forming processes that will lead to changes in the four VSP parameters critical to viability: abundance, productivity, spatial distribution, and genetic and life history diversity (see Section 6). Also identified were three conservation hypotheses that focus on hatchery and harvest issues in WRIA 9. The Necessary Future Conditions in WRIA 9 report (WRIA 9 and King County WLR) (Section 7) identifies the habitat conditions in the Green-Duwamish watershed and Central Puget Sound marine nearshore that are needed to support a viable Chinook salmon population. Among the next steps identified for linking the conservation hypotheses developed in Functional Linkages Project to the conservation goals identified in the Necessary Future Conditions Project, are four questions:

1. *Which VSP parameter or parameters most threaten long-term sustainability/viability?*

2. *Which kinds of habitat actions most directly affect which VSP parameters? (Consider temporal and geographical scale)*

    - *Abundance: habitat quantity and quality*
    - *Productivity: habitat quality*
    - *Diversity: habitat complexity and distribution*

- *Spatial Structure: habitat distribution*

3. *Which conservation hypotheses include the action(s) most likely to affect the limiting VSP parameter(s)?*

4. *Which conservation hypotheses and actions are expected to have the greatest effect?*

The answers to these questions are intended to guide a logical, stepwise decision-making process that identifies conservation hypotheses that have the greatest influence on VSP parameters. Implementation of these conservation hypotheses is expected to be the foundation of the WRIA 9 Habitat Plan. The Technical Memorandum entitled, Linking the Habitat Actions of the WRIA 9 Functional Linkages Conservation Hypotheses to Viable Salmonid Population Parameters – Draft (Anchor Environmental and Natural Resource Consultants 2004c) is the basis of much of the text that follows.

8.1.2. VSP Parameters Most Threatening Long-term Viability

This section addresses Question 1 noted above: Which VSP parameter or parameters most threaten long-term viability?

The WRIA 9 Technical Committee, using information from the historical and current conditions analysis (Sections 2 and 3), the change analysis (Section 4), salmon ecology and habitat use (Section 5) functional linkages (Section 6) and necessary future conditions (Section 7) addressed this question. The Technical Committee agreed that it is necessary to look at both short-term and long-term needs in evaluating the VSP parameters that most threaten viability. Based on the population performance findings related to both abundance and productivity, summarized in Section 7.2 (see also the sections on abundance and productivity goals and rationale), it is clear that there is a short-term concern about the number and productivity of natural origin recruit (NOR) spawners estimated by the TRT (2002).

For these reasons, the Technical Committee identified enhancing the productivity of the NOR population as the number one short-term priority. To enhance productivity, both spawning and rearing habitat quantity and quality will need to be addressed. Unfortunately, estimates of Chinook salmon productivity in WRIA 9 are highly uncertain, largely due to the confounding effect of hatchery fish spawning with natural origin recruits. Notwithstanding this uncertainty, analyses by the TRT suggest productivity may be exceptionally low. To remain viable, salmon populations must, at a minimum, replace themselves, and the depressed status of the Green-Duwamish Chinook indicates that productivity must increase. Actions that lead to enhanced productivity can have immediate effects on the population. Thus, productivity was judged the most threatening to Chinook viability in the near-term. More details on goals and rationale for productivity can be found in Section 7.

Over the long-term, spatial structure was identified as the VSP parameter most threatening the viability of the Green-Duwamish Chinook salmon population. Spatial structure was judged most threatening to the long-term viability of the population because much of the original watershed and associated spawning and rearing habitats have been diverted from the Green River or blocked by dams. Spatial structure of the Chinook population is now largely limited to middle and lower mainstem river habitats. Limited spatial structure reduces the potential for diverse genetic and environmentally-induced life histories. Limited spatial structure also increases the risk of population failure in response to catastrophic events that might occur in the future. Population responses to enhanced spatial structure, such as increased life history diversity, may require many generations to fully develop, and such a response may only occur if productivity of the habitat is reasonably high and if the genetic characteristics of the population are not overwhelmed by non-local stocks. With improvements to spatial structure, greater diversity will also follow. Addressing spatial structure and diversity is more of long-term process (i.e., it takes a long time to

address and to see changes), but it should begin now. More details on goals and rationale for spatial structure can be found in Section 7.

8.1.3. Habitat Actions and Conservation Hypotheses that Affect VSP Parameters

This section addresses Questions 2 and 3 noted above: *Which kinds of habitat actions most directly affect which VSP parameters (considering both temporal and geographical scale)?*

- *Abundance: habitat quantity and quality*
- *Productivity: habitat quality*
- *Diversity: habitat complexity and distribution*
- *Spatial Structure: habitat distribution*

Which conservation hypotheses include the actions most likely to affect the limiting VSP parameters?

When considering the effects of habitat actions on the four VSP parameters, it is important to recognize that the parameters are not completely independent. Perhaps the simplest way to think about the relationship is that productivity, diversity, and spatial structure interact to determine abundance. Another is that life history diversity, genetic diversity, and metapopulation organization reflect the adaptations of salmonids to their complex and connected habitats, which is, in turn, the foundation of productivity and ultimately, viability. In either case the range of "acceptable" values for life cycle productivity, diversity, and spatial structure depends on the size of the population. Actions should not be viewed in the narrow context of changing a single VSP parameter. Rather, the estimated benefit of a single habitat action (e.g., restoration of the connectivity of the mainstem to side channel habitat) would likely affect all four parameters.

While acknowledging the interdependence of the VSP parameters, generalizations can be made about the types of habitat actions that improve[3] each parameter. Such generalizations can be useful as a starting point for making the link between VSP parameters, salmonid life stage, and habitat.

Abundance or population size is perhaps the most straightforward of the VSP parameters and is a reflection of habitat quantity and quality. Increases in abundance can be achieved, for example, through increasing the availability of properly functioning habitat by such actions as opening up previously inaccessible portions of the watershed or restoring sediment transport processes that determine the availability and distribution of spawning substrates.

Productivity or population growth rate is a key measure of population performance in a species' habitat. In this way, habitat quality can be considered the primary habitat-related driver of productivity. The availability of properly functioning habitat to meet the ecological needs of salmon at each life stage from an incubating egg to a spawning adult will determine in large part a population's growth potential.

Genetic and life history diversity provide the mechanisms for a population to efficiently use existing habitat and to survive and adapt to short- and long-term changes in environmental conditions. Not surprisingly, providing a broad array of habitats and locations increases the diversity of habitat opportunities and, in turn, fosters enhanced species diversity. Life history traits that could potentially diversify through increases in habitat complexity and distribution include residence times (and outmigration times) and age structure of the population.

[3] In this context, the concept of improving VSP parameters refers to decreasing the long-term threat to sustainability/viability.

Spatial structure refers to the geographic distribution of individuals in a population unit and the processes that generate that distribution. The most straightforward element determining spatial structure is the accessibility of habitats; however, habitat quality will also influence whether an accessible spatial component functions sufficiently to be used by the species. Likewise habitat quantity, particularly when considering the availability of relatively small areas, will influence whether an accessible spatial component is found and/or selected by the species. For example, a small, isolated patch of suitable spawning gravel may not be encountered by upstream migrating adults.

The next step is to identify the conservation hypotheses that are most likely to affect each of the VSP parameters. A list of example habitat actions was prepared as part of the development of conservation hypotheses during Phase 2 of the Functional Linkages Project (Anchor Environmental and Natural Resources Consultants 2004) (see Table 6.1). While the suite of conservation hypotheses and habitat actions were identified through the evaluation and assessment of specific WRIA 9 watershed information, the identification of habitat actions to address Question 2 represents a more generic consideration of what measures will likely improve which VSP parameters. The latter set of habitat actions should therefore be considered theoretical. Ultimately, by comparing the VSP-derived habitat actions to those identified with the WRIA 9 conservation hypotheses, it is anticipated that priority can be placed on those conservation hypotheses that will most likely improve VSP parameters judged most limiting (productivity and spatial structure, see Section 8.1.2).

The identification of specific habitat actions that affect the VSP parameters was conducted in two steps. The first step entailed identifying potential changes in habitat conditions (e.g., increased spawning area or improved temperatures for upriver migrations) that would promote improvements to the VSP parameters (Table 8.1). While keeping in mind the interdependence of the VSP parameters and the generalizations of the types of habitat actions that affect each VSP parameter, this step was useful for focusing on specific aspects of habitat that can affect the population's condition for each VSP parameter.

The second step was to identify the specific types of habitat actions that would provide the changes in habitat condition described in Table 8.1. In this way, habitat actions that are expected to improve one or more VSP parameters were identified by directly considering the linkage between habitat and VSP. Table 8.2 provides a list of habitat actions that can affect VSP and the types of habitat improvements (e.g., quality, quantity, complexity, or distribution) they provide. The habitat actions are expressed as ways to improve habitat conditions, but protection of existing habitats that provide the various desired habitat conditions are equally important.

Table 8.1. Habitat Changes that Promote Improvements in VSP Parameters

Abundance	Productivity	Spatial Structure	Diversity
• More spawning area • More rearing area • Improved spawning habitat quality • Improved rearing habitat quality • Improve water quality during migration and outmigration • Improve migratory route conditions	<u>Keys to promoting egg incubation survival</u> • no siltation • no burial • no scour • no desiccation • favorable water flow/oxygenation conditions • reduce/minimize egg predation <u>Keys to promoting freshwater rearing survival</u> • predator refuge habitat • abundant prey resources • high flow refuge habitat to avoid being swept out • competition refuge habitat • favorable temperatures <u>Keys to promoting overwintering survival</u> • access to off-channel habitat • access to low energy habitat • adequate flows – no stranding, not swept out • available prey resources • predator refuge habitat <u>Keys to promoting outmigration/smoltification survival</u> • extended salinity transition zone • flow and habitat access to move between higher and lower salinity areas • predator refuge habitat • abundant prey resources	<u>Keys to promoting expanded spawning areas</u> • remove full barriers (e.g., dams) • remove ecological barriers (e.g., inadequate flows, high temperatures, low dissolved oxygen) • minimize anthropogenic increases to migration energy demands, such as partial barriers • suitable spawning flows providing appropriate depth and velocity • provide suitable spawning material • increase mainstem channel area (i.e. natural disturbance, removal of levees) <u>Keys to promoting expanded rearing areas</u> • suitable flows for access and exit (no stranding) • reduce/minimize “predation survival bottlenecks” (i.e., areas of high vulnerability to predators that lead to reduced recruitment from portions of the watershed) • suitable rearing flows providing appropriate depth and velocity	• expanded spatial structure which can increase time in river and create new subpopulations • accessibility of rearing habitat (see features in population growth rate section) that may promote fish staying in the river longer • absence of high flows that flush fish out to estuary (or out of areas with decent habitat) before intentional/directed movement by fish • availability of refuge habitat to increase residence time • favorable conditions for very early, peak, and very late fish in each life stage to promote extended periodicities

Abundance	Productivity	Spatial Structure	Diversity
	Keys to promoting nearshore survival • predator refuge habitat • abundant prey resources • extended salinity transition zone • access to suitable habitat along migration corridor • refuge from high energy conditions Keys to promoting marine/ocean survival • abundant prey resources Keys to promoting adult spawning migration survival • suitable temperatures • suitable flows for migration • expanded spawning habitat (quantity and quality) • minimize pre-spawn mortality • minimize anthropogenic increases to migration energy demands, such as partial barriers • reduce predation risks	• increase refugia (i.e. overhanging streamside vegetation, shallow slow-moving water areas)	

Table 8.2. Types of Habitat Improvements Provided by Habitat Actions

Habitat Action	Type of Habitat Improvement			
	Quality	Quantity	Complexity	Distribution/ Connectivity
Allow high flows and the reconfiguration of shoreline levees to create side channel and off channel habitats	✓	✓	✓	✓
Maintain flows during spawning season that maximize available habitat with suitable depths and velocities	✓	✓		
Maintain flows that maximize available habitat with suitable depths and velocities for rearing	✓	✓		
Maintain flows that provide suitable depths and velocities for migration	✓	✓		
Maintain flows to allow fish to remain in river and estuarine transition zone without flushing them out of river	✓			
Maintain suitable flows in river to avoid stranding	✓	✓		
Maintain suitable flows in river to keep all spawning areas wetted throughout incubation period	✓			
Minimize the occurrence of scouring flows during incubation period	✓			
Protect cold water sources	✓			
Provide flows that allow access to tributaries or redistribute alluvial fan that may act to limit access		✓	✓	✓
Provide flows that maintain suitable dissolved oxygen levels and do not exacerbate warm temperatures	✓			
Install LWD to provide cover, deep pools of cool water, energy/predator refugia, habitat for prey species, organic material for food web, and location for spawning size gravels to occur	✓	✓	✓	
Provide embayments and unmodified non-natal tributary mouths that provide feeding opportunities and energy/predator refugia	✓	✓		
Remove armor and fill to increase availability of shallow habitats for prey production and juvenile salmonid foraging and predator refuge	✓	✓		
Remove or isolate contaminated sediments	✓			
Add riparian cover to shade the river, slow/prolong upland runoff, and provide cover, LWD, terrestrial prey items, and organic material to aquatic food web	✓	✓	✓	
Decrease sediment load and turbidity by keeping riparian areas vegetated	✓			
Decrease sediment load that decreases ability to visually locate potential prey items	✓			

Habitat Action	Type of Habitat Improvement			
	Quality	Quantity	Complexity	Distribution/ Connectivity
Decrease sediment load to reduce physiological burden to fish and reduce possibility of egg or food source burial	✓			
Increase sediment load to decrease ability of potential predators to locate juvenile salmonids	✓			
Increase sediment recruitment processes which provide more spawning gravels	✓	✓	✓	
Allow LWD to remain on beach to provide structure for refuge	✓		✓	
Provide natural beach slopes and substrates in nearshore that provide feeding opportunities and refuge from predators	✓	✓		
Restore natural estuarine depths and off channel habitats to reestablish a more natural estuarine transition zone from freshwater to saltwater	✓	✓	✓	✓
Decrease input of nonpoint source pollutants in stormwater runoff	✓			
Provide access to side channels that provide energy/predator refugia and productive prey resources	✓	✓	✓	✓
Provide additional off channel habitat in estuarine transition zone to provide fish with area to rear and extend residence time	✓	✓	✓	✓
Provide upstream and downstream fish passage around dams		✓		✓
Reconnect floodplain and wetlands by removing levees to dissipate energy during high flows, provide side channel habitat	✓	✓	✓	✓
Reduce modifications in watershed that alter the hydrologic cycle and connectivity of surface and groundwater	✓	✓		
Remove culverts and tidegates that may limit accessibility of potential spawning habitats		✓		✓
Remove dam(s)		✓		✓
Restore natural sediment transport processes which support availability of intertidal rearing habitat for juvenile salmonids and spawning habitat for forage fish	✓	✓		
Provide connection to upland sediment sources (bluffs) and riparian vegetation that contribute to productive foraging opportunities in nearshore	✓	✓		
Reduce amount of habitat used by hatchery strays to ensure best habitats are available for natural fish		✓		

Reducing risk associated with low productivity and limited spatial structure, as well as low abundance and low diversity, will entail implementing a suite of habitat actions that address the variety of limiting factors that are influencing the species viability in the Green-Duwamish River. Actions addressing spatial structure include readily identifiable "fixes," such as re-opening salmonid access to habitat in the Upper Green River subwatershed above the dams. Other actions to enhance spatial structure and diversity involve creation or enhancement of spawning and rearing habitats within reaches currently used by Chinook salmon. Table 8.3 presents the conservation hypotheses from the Functional Linkages Project (Anchor Environmental and Natural Resources Consultants 2004) that entail actions which may provide salmon access to currently inaccessible habitats and actions that enhance spatial structure within habitats presently used by salmonids.

Productivity can be enhanced by a wide range of habitat actions that enhance habitat quality (see Habitat Quality column in Table 8.2). However, it is important to note that strict quantitative relationships between most habitat quality features and salmon productivity or survival are lacking (Anchor Environmental and Natural Resources Consultants 2003). Nevertheless, considerable qualitative information is available on effects of habitat quality on salmon productivity. The Functional Linkages Phase 2 Report indicated that 25 of the 29 habitat-based conservation hypotheses are expected to affect productivity (Table 8.4). Prioritization of these hypotheses may ultimately rely on the rationale and data presented in the detailed conservation hypotheses presented in the Appendix to the Functional Linkages Phase 2 Report. Not surprisingly, there is an overlap of hypotheses that will affect spatial structure and productivity.

Table 8.3. Draft Habitat Conservation Hypotheses That May Affect Spatial Distribution By Extending Access to New Habitats or Enhancing Spatial Structure in Currently Accessible Reaches

ID	Hypothesis
Conservation Hypotheses that Provide Access to Currently Inaccessible Habitats	
Up-1	Establishing/restoring Chinook salmon access above HHD by providing passage upstream (trap and haul) beyond HHD and the reservoir for natural origin Chinook and downstream passage for the progeny as well as first generation hatchery fry will increase habitat quantity and expand salmon spatial structure. (Alternate Hypothesis: Augmenting restoration of salmon populations above HHD by re-introducing spring Chinook from a neighboring river system (possibly White River) will expand Chinook distribution, diversity, and enhance abundance in the river.) (Alternate Hypothesis: Restoring salmon above HHD without the use of hatchery outplants or returning hatchery adults will recover Chinook without bypassing important evolutionary processes (i.e., the selection of the fittest adults for spawning, and juveniles for incubation). *Note: Final decisions on which fish to pass upstream are dependent upon NOAA Fisheries, USFWS, and the co-managers (WDFW and Muckleshoot Indian Tribe)*
Mid-6	Restoring Chinook salmon access between the Tacoma Diversion Dam (TDD) and Howard Hanson Dam (HHD) by providing passage upstream and downstream at the TDD for natural origin Chinook will increase habitat quantity and expand spatial structure.
Up-3	Establish bull trout population above HHD by providing passage upstream (trap and haul) beyond HHD and the reservoir for returning adults and downstream passage for the progeny as well as hatchery fry will increase habitat quantity and expand spatial structure. *Note: Final decisions on which fish to pass upstream are dependent upon NOAA Fisheries, USFWS, and the co-managers (WDFW and Muckleshoot Indian Tribe)*
All-3	Protecting and improving access to tributaries will increase the quantity of available habitat, particularly for juvenile Chinook and coho salmon, and lead to expanded salmon spatial distribution, greater juvenile salmon growth, and higher survival.
Low-4	Modifying the Black River Pump Station to allow fish passage will increase habitat quantity and lead to greater juvenile salmon residence time and growth.
Conservation Hypotheses That May Enhance Spatial Structure in Currently Accessible Reaches	
All-4	Allowing natural disturbance-type flows in a relatively unconstrained river channel will enhance habitat diversity and provide habitats that can support spawning and rearing salmon at a greater variety of flow conditions (compared with high flows in a constrained channel), thereby leading to expanded salmon spatial distribution, greater juvenile salmon growth, and higher survival).
Duw-4	Protecting, creating, and restoring habitat that provides refugia (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.
Low-1	Protecting and creating/restoring habitat that provides refugia (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.
Mid-1	Protecting and creating/restoring habitat that provides refugia (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.

Table 8.4. Draft Habitat-Based Conservation Hypotheses That May Affect Productivity

ID	Draft Conservation Hypothesis
All-1	Protecting and improving water quality (e.g., temperature, dissolved oxygen, turbidity, and chemical contamination conditions) by addressing point and non-point (specifically stormwater runoff and agricultural drainage) pollution sources will enhance habitat quality and lead to greater juvenile salmon growth, disease resistance, and survival. Improved water quality will also enhance survival of adult salmon, incubating salmon eggs, and salmon prey resources, such as forage fish.
All-2	Protecting and improving riparian zone conditions by adding native riparian vegetation will enhance habitat quality by improving water quality, stabilizing stream banks, providing overhanging vegetation and large woody debris (LWD), and contributing organic matter, nutrients, and terrestrial prey items, thereby leading to greater juvenile salmon growth and higher survival.
All-4	Allowing natural disturbance-type flows in a relatively unconstrained river channel will enhance habitat diversity and provide habitats that can support spawning and rearing salmon at a greater variety of flow conditions (compared with high flows in a constrained channel), thereby leading to expanded salmon spatial distribution, greater juvenile salmon growth, and higher survival.
All-5	Preserving and protecting against watershed and upland impacts by implementing Low Impact Development techniques, including minimizing impervious surfaces, will maintain habitat quality by helping maintain flow and reduce sedimentation, thereby leading to greater salmon survival.
All-6	Preventing new bank/shoreline armoring and fill and removing existing armoring, fill and other impediments (e.g., levees) will enhance habitat quality and quantity and lead to improved juvenile salmon survival, spatial distribution, and diversity.
All-7	Maintaining adequate flows during low flow periods will improve water quality and enhance rearing and spawning habitat quality and quantity, and upstream migration/holding conditions for returning adults, thereby leading to greater survival.
Duw-1	Expanding and enhancing the Duwamish estuary, particularly vegetated shallow subtidal and intertidal habitats and brackish marshes by restoring dredged, armored, and filled areas, will enhance habitat quantity and quality and lead to greater juvenile salmon residence time, greater growth, and higher survival.
Duw-2	Protecting and improving sediment quality will enhance habitat quality and lead to greater juvenile salmon growth, disease resistance, and higher survival.
Duw-3	Enlarging the Duwamish River estuarine transition zone habitat by expanding the shallow water and slow water areas will enhance habitat quantity and quality of this key Chinook salmon rearing area, leading to greater juvenile salmon residence time, greater growth, and higher survival.
Duw-4	Protecting, creating, and restoring habitat that provides refugia (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.
Low-1	Protecting and creating/restoring habitat that provides refugia (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.
Low-2	Restoring and enhancing sediment recruitment (particularly spawning gravels) by reconnecting sediment sources to the river will reduce channel down-cutting, increase shallow habitats, improve access to tributaries, and improve spawning habitat, thereby leading to greater juvenile salmon residence time, greater growth, and higher survival.
Low-3	Preserving and maintaining groundwater inflow from historical White River channel will contribute to maintaining river flows and good water quality, thereby leading to greater juvenile and adult salmon survival.
Low-4	Modifying the Black River Pump Station to allow fish passage will increase habitat quantity and lead to greater juvenile salmon residence time and growth.

ID	Draft Conservation Hypothesis
Mid-1	Protecting and creating/restoring habitat that provides refugia (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g., mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.
Mid-2	Protecting against watershed and upland impacts by implementing Low Impact Development techniques (see All-5) will be particularly beneficial in the sub-watersheds of tributaries that provide spawning (e.g., Newaukum and Soos Creeks) and/or rearing habitat (e.g., Jenkins and Covington Creeks) will increase habitat quality and quantity and promote utilization of non-mainstem habitats and prevent creating additional stressors that limit survival.
Mid-3	Protecting and restoring natural sediment recruitment (particularly spawning gravels) by reconnecting sediment sources to the river will help maintain spawning habitat.
Mid-4	Preserving and restoring spawning and rearing habitat in lower Newaukum and Soos Creeks will increase habitat quality and quantity, thereby increasing productivity and spatial structure of Green River Chinook salmon.
Mid-5	Maintaining regional groundwater recharge and base flows to the mainstem Green River through forest retention and Low Impact Development will maintain spawning and rearing habitat.
Near-1	Protecting and improving sediment quality, particularly in Elliott Bay will enhance habitat quality and lead to greater juvenile salmon growth and higher survival.
Near-2	Protecting and increasing the availability of vegetated shallow nearshore and marsh habitats will enhance habitat quantity and quality and lead to greater juvenile salmon residence time, greater growth, and higher survival.
Near-3	Protecting and restoring nearshore sediment transport processes by reconnecting sediment sources and removing shoreline armoring that impacts sediment transport will lead to greater prey production, greater juvenile salmon growth and higher survival.
Near-4	Protecting and expanding forage fish spawning areas by maintaining/ increasing high intertidal zone access and maintaining/ increasing availability of suitable substrate sizes will lead to greater juvenile salmon growth and higher survival.
Near-5	Protecting and enhancing pocket estuaries (i.e., small non-natal smaller estuaries, lagoons, and spits) and salmon-bearing and non-salmon bearing tributary mouths by maintaining/ restoring tributary mouths will increase quantity of key habitat and lead to greater juvenile salmon growth and survival.
Up-2	Protecting and restoring/enhancing habitat along the upper Green River mainstem and major tributaries (e.g., North Fork, Smay Creek) by restoring the riparian corridor and logging roads will enhance habitat quality and lead to greater residence time and survival (after the establishment of populations above HHD]).

8.1.4. Non-Habitat-Based Conservation Hypotheses That May Affect the Limiting VSP Parameters

Although management of hatchery production and harvest resides with NOAA Fisheries, WDFW and the Indian Tribes, both activities pose risks to natural-origin Chinook salmon and should be considered in the WRIA 9 Habitat Plan. There are considerable data indicating that hatchery production and harvest rate can significantly affect productivity (and diversity) of natural salmon populations. A key question when developing the WRIA 9 Habitat Plan is whether to emphasize conservation of naturally- spawning Chinook salmon along with their higher productivity and greater potential to adapt to changes in habitat and climatic factors, or whether to maximize production of hatchery fish to enhance harvest opportunity (Anchor Environmental and Natural Resources Consultants 2004b).

Shared Strategy and the PSTRT have asked WRIA 9 to assess what is necessary to ensure the long-term viability of the natural spawning population (Shared Strategy 2001, PSTRT 2003). If this is maintained as a top priority, then minimizing interactions between hatchery and natural salmon may be necessary. Salmonids are opportunistic and resilient and are likely to use restored or improved habitat in the short term if it is suitable. However, WRIA 9 population performance findings indicate that Green River NOR Chinook may continue on a downward trajectory unless harvest and hatchery issues are addressed.

Several hatchery and harvest-related hypotheses identified in the Functional Linkages Phase 2 Report (see Section 6) have the potential to enhance productivity of natural Chinook salmon. Non-Habitat Hypothesis 1 identified the use of live-capture harvest techniques to reduce the number of hatchery adults reaching the spawning grounds. This action has the potential to significantly reduce hatchery fish straying to the spawning grounds (approximately 60% of spawners in river are currently of hatchery origin), thereby enhancing productivity of natural spawners that compete for spawning habitat. This action would also serve to limit the interbreeding of hatchery- and natural-origin fish, and hence limit the production of progeny exhibiting reduced survival. Moreover, the large number of hatchery fish on the spawning grounds currently confounds evaluation of productivity of the natural population; therefore removal of stray hatchery fish would enhance accuracy and precision of productivity estimates. Accurate measures of productivity are needed to evaluate other conservation hypotheses that may be employed.

Non-Habitat Hypothesis 2 involves a variety of hatchery operation options to minimize interactions between hatchery and natural Chinook salmon at both juvenile and adult life stages. Studies in 2002 and 2003 suggest that the release of approximately 3 million hatchery Chinook salmon leads to reduced growth and displacement of natural Chinook salmon in mainstem and off-channel habitats in the Duwamish estuary (Nelson et al. 2004, Ruggerone and Jeanes 2004). Productivity of natural Chinook salmon may be enhanced by reducing competition among juveniles for food and space and by enhancing the attractiveness of the hatchery to returning adults (i.e., reduce competition on spawning grounds).

Non-Habitat Hypothesis 2 involves reducing harvests of non-salmonid marine species (Dungeness crab, forage fish), that provide important prey to Chinook salmon in Puget Sound. Productivity of Chinook salmon may be enhanced if this action leads to greater growth of Chinook salmon. This action may have its greatest effect during periods when prey productivity in the Puget Sound region appears to be relatively low (e.g., 1990s).

8.2. HABITAT PLANNING – NEXT STEPS

The next step for the WRIA 9 Technical Committee will be to prioritize conservation hypotheses to be implemented as initial actions to improve productivity and spatial structure and to achieve the Necessary Future Conditions identified in Section 7. This will be done in consideration of Question 4 noted above:

Which of the conservation hypotheses are expected to have the greatest effect on the VSP parameters posing the greatest risk?

A recommended approach for identifying which of the conservation hypotheses are expected to have the greatest effect is to critically consider the rationale and scientific data supporting each hypothesis (provided in Appendix A of Functional Linkages Phase 2 Report) as well as the linkages between habitat actions and VSP that were identified above. In doing so, it is anticipated that certain hypotheses will have a stronger scientific basis and therefore a more defensible and clear "logic train" for recommending those hypotheses as being most likely to positively affect the most threatening VSP parameters.

The next step, Task 8 of the habitat planning process, is the development of habitat management strategies. Habitat management strategies will be developed for each subwatershed and for the watershed as a whole and will comprise Section 8 of the Habitat Plan. During this step, the four habitat management strategy types–protect, restore, rehabilitate, substitute–NRC 1992, PSTRT 2003) will be evaluated and recommended as appropriate for achieving subwatershed habitat conditions. Considerations in applying these alternative habitat management strategies include certainty of success in achieving VSP parameters, ongoing resource inputs to achieve viability, and the level of monitoring and evaluation required (PSTRT 2003).

The habitat management strategies will provide the updated technical strategy for WRIA 9 and will supersede the Technical Strategy for Salmonid Conservation and Recovery (2003). Because this task is technically based, the Technical Committee will provide leadership. The Planning Work Group will provide input and the Steering Committee must ultimately approve the strategies. The development of habitat management strategies will be organized around the habitat attributes or processes identified in the conservation hypotheses and necessary future conditions. Consistent with TRT guidance and to provide a clear train of logic, the work will also identify VSP parameters addressed, sequencing of the elements within the strategy, and how the strategy addresses uncertainties and preserves options.

Research, monitoring and evaluation, and an adaptive management program will be key components of the WRIA 9 Habitat Plan and will help ensure successful implementation. Monitoring will allow measurement and evaluation of the success of actions aimed at protecting and restoring habitat. Adaptive management will allow use of monitoring information and results from past actions to continually improve future management actions. The overall approach to monitoring and adaptive management was summarized in the WRIA 9 Technical Strategy (WRIA 9 Technical Committee 2003). This information will be used and further developed to provide the comprehensive approach to monitoring and adaptive management in the WRIA 9 Habitat Plan.

With completion of the Strategic Assessment and subsequent development of habitat management strategies, the habitat planning process moves into the policy synthesis stage. Suites of management actions and alternatives will be developed and social and economic values will be integrated. The Steering Committee will select priority actions to conserve habitat and develop an implementation strategy. A draft Habitat Plan will be produced by May 2005 and approval by the WRIA 9 Forum will occur by the end of 2005.

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